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The Rothamsted Memoirs on Agricultural Science

CROPS, PLANT GROWTH, PLANT PRODUCTS, ACTION OF MANURES

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THE GILBERT WHITE FELLOWSHIP

SINCE GILBERT WHITE— TWO CENTURIES OF CHANGE.

BY SIR E. JOHN RUSSELL.

IN 1927 your late President, Sir Daniel Hall, described to you with his characteristic brilliancy the times in which Gilbert White lived and worked. "To us looking back," he said, "those seventy years of White's life seem a period of incredible serenity and stability—the lull before the storm that has brought about the wreck of the faiths, customs and policies that men then held dear."

I am attempting to-day to give you some account of the way the "storm"—to use Sir Daniel's word—proceeded in regard to some of the work dear to Gilbert White, and as no one person could hope to trace all the changes that have happened I shall confine myself to the changes in the method of studying the growing plant.

The general method adopted by Gilbert White was close unbiassed observation with complete freedom from any preconceived ideas. This was a great advance on some of the older observers who began with some hypo-

thesis—often fantastic—and proceeded to make their observations fit it: or else copied more or less faithfully from travellers' tales without sifting the evidence. Topsell is the great example of the older writers: his "History of four-footed beasts and serpents"* was still a standard natural history in Gilbert White's time: it still survives for its quaintness and humour:† it seems to us to embody the medieval spirit just as clearly as Gilbert White embodies the modern spirit. The result has shown that this direct, accurate observation of Nature, simply recorded without flourish of words and without obtruding of one's own personality, is a sure way to confer perpetual youth upon one's book.

The method seems simple, yet it is very laborious. Gilbert White himself says‡ "Though there is endless room for observation in the field of nature, which is boundless, yet investigation (where a man endeavours to be sure of his facts) can make but slow progress; and all that one could collect in many years would go into a very narrow compass."

No wonder the method is so rarely used and books like Gilbert White's are so few.

Moreover even in the best hands the method is limited. It had been used by a long sequence of careful observers to study that very important subject, the food of plants, but it had led them entirely astray—not through their own fault but through its inherent limitations. One of the most definite of all observations is the fact that farmyard manure increases the growth of plants. It contains organic matter of a recognisable kind. Soils rich in organic matter of apparently the same kind also

* First issued in two parts in 1607 and 1608, then re-issued together in 1658; it contains much that is simply taken from Conrad Gesner.

† Miss A. M. Tudor, in "A little book of birds and beasts" (The Medici Society 1931) has culled some of Topsell's choicest fragments and made out of them a charming little volume.

‡ Letter V.

increase plant growth in the same way; so do other substances such as rotted plant residues, which contain apparently the same organic matter. What more simple and apparently more convincing than the deduction that this organic matter which was called "humus" is the food of plants? The deduction was tested by chemically analysing plants and humus: the only process then available was a distillation; it yielded a tarry liquid of apparently the same kind from both plants and humus.

The reasoning seemed so sound, that so long as the observational method was the only one available it was accepted, and humus was supposed to be the food of plants.

Fortunately for science, another method was springing up in Gilbert White's time—the experimental method—and this, linked with his observational method, has led to our great modern advances. It was not entirely new: it had been used a good deal in the 17th Century, but then came a long lull; it revived and while White was writing his letters between 1767 and 1781 some of his contemporaries were experimenting.

The experimental method as it was then adopted however, was not the same as a good investigator would generally use now. There was rarely a definite plan or purpose in the experiments: a man would try something to see what happened: then he would try something else. It was rather like firing a gun out of a window on a dark night: something might be hit or it might not: one could never tell. The early experiments on plant growth were with a few brilliant exceptions (such as van Helmont's classical experiment) all of this nature. They served the purpose, however, of building up a fund of observations which could not otherwise have accumulated. Home in 1757—10 years before White's first letter—grew plants in pots and added to the soil some salt or other substance to see how it acted: apparently he tried

everything he could think of. Saltpetre, Epsom salt (magnesium sulphate), potassium sulphate and oil all increased plant growth; all, therefore, were described as plant foods. A greater and more brilliant figure, Priestley, was working while Gilbert White wrote: he used this same 'hit or miss' method: indeed he justified it on an analogy which most experts would feel to be false.

'I do not think it all degrading to the business of experimental philosophy,' he writes, 'to compare it, as I often do, to the diversion of hunting, where it sometimes happens that those who have beat the ground the most, and are consequently the best acquainted with it, weary themselves, without starting any game, when it may fall in the way of a mere passenger.'*

However, the method was not very good. Some men could work it well: some have a genius for getting results, but that, like Gilbert White's gift, is not for all men. A few like Mayow and Black had a genius for close reasoning and so could join one experiment to another in logical sequence. But only a few could ever do this; even to-day this gift is rare. Some other method was wanted more suitable for ordinary men.

Gradually it was realised that the experimental method to be most effective must be quantitative. An experimental investigation must be something like the drawing up of an accurate balance sheet in a business house. The accounts must all be added up, every item must be accounted for, if anything remains over, the explanation must be sought diligently. In a balance sheet adding up to £100,000 an error even of £1 would not be permitted, not because the £1 is specially important, but because it shows that something is wrong on one or both sides and the error may involve hundreds or thousands of pounds. So in a scientific investigation the figures must add up properly and even small discrepancies

* History of the present state of electricity, 1776.

must be explained, not necessarily because of any intrinsic importance, but because they may conceal big errors. In our particular subject of plant growth the quantitative method had been used in those experiments by van Helmont and later on (1674) by Mayow and (1699) by Woodward: it was now revived and used in 1804 with marked effect by Théodore de Saussure. He started with great advantages over his predecessors. Chemistry had attained a considerable degree of development: many of the elements were known: methods of analysis had been devised: the underlying connecting thread furnished by the Atomic theory had already been woven. It was known that plants took up food stuffs through their roots: indeed everything was supposed to enter in this way. It was also known that plant leaves did something to the air but no one was quite sure what. Priestley had shown that plants purify the air made noxious by animals. Scheele declared that they vitiated the air just like animals do: Priestley repeated his experiments and failed to obtain the same results as before. It was just the sort of tangle that a modern scientific worker would enjoy. There was at the end of the 18th century a good school of plant physiology at Geneva led by Senebier, de Saussure and his son Théodore. The two older men thought a good deal about this business of plants and air but they could not get far with it because the composition of the air was not known and combustion had not been explained. By the time Théodore was ready to work Lavoisier had made his famous discoveries, had explained oxidation and combustion and shown the relationship between oxygen and carbon dioxide. Théodore was therefore in a better position than any of his predecessors for studying the problem. By a sound instinct he recognised that he must make his studies quantitative. He therefore enclosed plants in vessels containing air or known mixtures of air and carbon dioxide: he analysed the air before and

after the plants had been enclosed and calculated the exact amount of change that had occurred. He showed that carbon-dioxide was taken up by the plant in daylight but not in darkness: the carbon was retained by the plant and the oxygen was liberated. In darkness no carbon dioxide was taken up but it was given out by the plant. He showed by analysis that the amount of dry matter gained by the plant during its period of growth was so nearly the same as the amount taken from the carbon dioxide and water that very little was left unaccounted for: assimilation of organic matter through the roots, previously supposed to be the chief source of supply, could account for very little. The roots had, however, another action which was altogether different from that previously supposed: they absorbed nitrogen compounds and ash constituents, both of which were essential to plants. Théodore de Saussure's book* is one of the classics of science; it is classical not only because of *what* he discovered but still more as showing *how* he made his discoveries. He first introduced the idea of a balance sheet into scientific investigations. Like other classical works however, it was for long neglected.

de Saussure had worked in the laboratory. Two other workers, an ingenious minded Frenchman J. B. Boussingault and C. G. B. Daubeny, the brilliant Professor of Botany and Agriculture at Oxford, simultaneously and quite independently made experiments on plants growing in the open. Daubeny's work I shall discuss later: Boussingault's had more direct bearing on the question of plant growth and especially of crop production. Starting about 1834 he grew a rotation of plants in the field in the ordinary way, analysed them at the end of each season, analysed also the manure supplied and at the end of five years made up a balance sheet: setting out on one side the amounts of dry matter, carbon, hydrogen, oxygen, nitrogen and mineral matter

* Recherches chimiques sur la Végétation, Paris, 1804.

supplied in the manure and on the other side the quantities of each of these present in the crops. His balance sheet was not complete because he could not analyse the soil, but as the soil just about maintained its fertility through the added manure he supposed it could not have altered much in any essential constituent. He showed that large amounts of carbon, hydrogen and oxygen remained unaccounted for, except on de Saussure's view that they came from the air. On the other hand the nitrogen supplied by the manure and the nitrogen in the crop more nearly balanced: it was unnecessary to assume any large supply coming from other sources. The mineral matter account did not balance: there was a considerable deficit indicating that much had been taken from the soil.

Science in those days was not well organised and not at all well documented. The researches and methods of de Saussure and of Boussingault were not widely known and so the old ideas persisted in spite of the new knowledge. Botanists did not necessarily know of the advances in chemistry and agriculturists knew nothing of either. The next great step forward was the organised recording of scientific results: the establishment of journals in which they could be published, the indexing of these journals and the periodical publication of critical summaries of new knowledge.

There had for many years been some scientific journals. The oldest now existing is the *Philosophical Transactions of the Royal Society* which goes back to 1665. This, however, dealt with only a small part of the available material. Fellowship of the Society was then, as now, rigidly restricted, so that it did not afford full scope for discussion. One of the most active agents for the organisation of Science was the *British Association for the Advancement of Science*, founded in 1831. From the outset it proceeded to organise enquiries into or discussions on the important problems, and at its first meeting at York, Prof. Lindley presented by request an

“account of the principal questions under discussion in Botanical Science” among which he included root excretions and the supposed necessity for a rotation of crops. It was recognised that experimental work was needed, and the study of crop rotation was undertaken by Prof. Daubeney at Oxford in 1834. Farmers also were beginning to organise their search for information: the oldest agricultural Society, the Bath and West, had appointed a chemist as far back as 1806, but the first systematic list of problems requiring investigation was that drawn up by the Royal Agricultural Society and published on its foundation in 1838: a list which is so good and so comprehensive that it still serves as a good research programme.

These changes in the 1830's ushered in a revolution in 1840. For our subject 1840 is a critical date: it is, so to speak, the 1066 of agricultural science. In that year Liebig brought together the observations and deductions of de Saussure, Boussingault and others, and interpreted them in the light of the new science of organic chemistry. His *Chemistry in its application to Agriculture and Physiology* (1840) is another scientific classic because of the way in which he assembles large numbers of observations, marshals them in proper order and shows the irresistible conclusion to which they point. He did not himself add new knowledge, and he made some mistakes as every courageous scientific worker must do, but he showed the position that had already been reached and set out the results in a series of laws or principles that not only summarised existing knowledge but opened the way to new knowledge by inviting discussion and further investigation. Broadly speaking his conclusions were:—

(1) Plants need for their growth supplies of carbon, oxygen, hydrogen, nitrogen, phosphorus, and the alkalis and alkaline earths, potassium, sodium, calcium and magnesium.

(2) Of these the carbon, some of the oxygen and the nitrogen come from the air, the hydrogen and the remaining oxygen came from the water, the phosphorus and other ash constituents from the soil.

(3) Since the amount of air is indefinitely great, plants can never be short of carbon, oxygen and nitrogen, and it is unnecessary to supply these in the manure.

(4) The full amounts of mineral constituents needed may, however, not be contained in the soil. In that case they must be supplied by the manure or the plant will fail to make good growth. The lack of growth will be proportional to the lack of the food stuff: if you can discover the food stuff present in the minimum amount and supply that as manure you will increase crop growth.

(5) The composition of the plant ash shows what elements it needs, and approximately in what proportions: if a substance is present in the plant in a certain quantity it is there because the plant needs it in that quantity.

From all this he drew the very important practical conclusion that farmyard manure and all other manures are valuable only because of the mineral matter they supply, and not because of their organic matter. It would be more effective and far cheaper to supply the mineral matter direct as salts of potassium, sodium, etc.

This was the first time in history that a scientific worker had made so important and revolutionary a recommendation for practical agriculture. It could not pass unheeded: Liebig was too distinguished a chemist to be ignored, and he wrote so vividly, and dealt out such terrific blows, that no one who begins to read his books is likely to stop till he has finished them.

A little before this time a young Englishman, John Bennet Lawes, had come (1838) into his estate at Rothamsted, and being fond of making experiments he tried

the effects of various substances on growing plants. His first experiments were very much like those of Home in 1757: he tried a variety of things more or less at random and found that plant growth was increased by sulphate of ammonia and by calcium phosphate, especially after treatment with sulphuric acid: he satisfied himself completely on these two points. This calcium phosphate result was particularly gratifying because it solved a problem that had long puzzled farmers; why do bones act better on some soils than on others? Lawes argued that the plants need their phosphate in *soluble* form and that bones dissolve more readily in some conditions than in others. If the bone phosphate is made soluble before addition to the soil it is effective on all soils that need phosphate. His discovery had the further merit that it enabled him to utilise the great quantities of mineral phosphate then recently discovered. He patented his process in 1842, bought mineral phosphate, treated it with sulphuric acid, thereby converting it into the soluble phosphate then called "superphosphate of lime," and sold the resulting mixture as manure. Thus was founded the Artificial Fertiliser industry which has since attained colossal dimensions. But Lawes did not stop here. He had spent a year at Brazenose College, Oxford, and there attended lectures by Daubeny and saw the experiments Daubeny was doing on the rotation of crops. The observational method had shown that crops generally grew better in a rotation, when one follows another of a different sort, than in a sequence, where one follows another of the same sort. The explanation widely accepted was that plants excrete a substance harmful to themselves but not necessarily harmful to other varieties of plants: it was supposed to disappear after a time. Daubeny tested this idea. He set up garden plots on which he grew certain plants year after year on the same land, while others were grown in a rotation. Plants and soils were analysed to study the

uptake of the mineral matter and to see how far losses from the soil balanced the gains by the plant. The crops grown in sequence yielded less, and obtained less food from the soil, than those grown in rotation but the difference was too small to justify the assumption of any toxin. The experiment is very difficult to carry out and indeed it has not been satisfactorily made yet. The subject still needs further examination. Daubeny's experiment was important not simply for disproving a false assumption but even more because it seems to have suggested the plan for the field experiments which Lawes started when he left Oxford and which are still continued today, constituting the most interesting and the richest in yield of data in the whole world. Lawes set aside four fields, on one of which he grew the four common English crops in their usual rotation—the Norfolk rotation, wheat, swedes or turnips, barley, clover—in the other fields he grew each of these crops in sequence, wheat continuously in Broadbalk, barley in Hoos, clover in Hoos and swedes in Barnfield. This part of the plan is identical with Daubeny's. He divided each field into plots one of which had no manure, one had farmyard manure, one had the mixture of minerals but no nitrogen compound, as recommended by Liebig, and another had the minerals plus a nitrogen compound (sulphate of ammonia, then obtainable cheaply from gas works) which Lawes' early experiments had suggested was necessary. The crops were analysed to see what they had taken up from the soil and from the air, again as in Daubeny's scheme.

Lawes was thus carrying out two enterprises: his artificial fertiliser factory in London and his experimental farm at Rothamsted. He was a very capable organiser and did not attempt to do the details himself. For the Rothamsted experiments he secured the collaboration of a young chemist, Joseph Henry Gilbert. The results of his early pot experiments and these new field experiments

were not in accordance with the expectations of Liebig. The minerals alone were not sufficient: nitrogen had to be added if the yields from artificials were to equal those from farmyard manure. The yields of crops increased, not with increasing mineral supply as Liebig had supposed, but with increasing nitrogen supply. Further, the composition of the ash did not afford guidance about the manuring: turnips contained in their ash much potash and little phosphate, but their manurial requirements were for much phosphate and little potash. It was an age when men loved controversy, and Lawes, quite unabashed at the prospect of standing up against one of the most distinguished scientific men of the day, boldly published his criticism of Liebig's so-called Mineral theory. Liebig replied not with experiments but with heavy invective: "The experiments of Mr. Lawes are entirely devoid of value The mixtures being made without any understanding of the case and without reflection, as if they had been determined by mere chance His conclusions are destitute of all foundation in logic or in facts."*

Lawes replied with more experimental data giving always however the same results. The last word of course was with the experiments. Fortunately for us Gilbert was exceedingly persistent and encouraged the repetition of the same experiments year after year on the same land long after the original problems had been solved and the original controversy was dead. To their last days Lawes and Gilbert carried the field experiments on, and with true instinct Lawes set up a Trust and endowed it so that they could be continued in perpetuity. They have long been classical and they continue to furnish invaluable and often unique material to investigators. A field experiment continued long enough is bound to give valuable results even though the original plan may have been defective.

* Principles of Agricultural Chemistry, 1855.

This method of controversy with the appeal to experiment was used a great deal during the 19th century. The British Association meetings encouraged it, the times suited it. The daily paper was unusual in an ordinary household; the network of news systems was not yet established: there was no varied supply of richly spiced and nicely alternating murders, divorces, kidnappings, sporting events, sex appeals to stimulate and then to jade the appetite: people could still be astonished and amazed at a new investigation or a new idea. The old was still firmly rooted: the new moved in but slowly. All branches of science had their controversies, and they cleared away an enormous amount of error. Most of the controversies attracted but little attention outside professional circles. The exceptions were those dealing not with things but with man—"the ascertainment," to quote Huxley "of the place which Man occupies in nature and of his relations to the Universe of things. Whence our race has come: what are the limits of our power over nature, and of nature's power over us; to what goal we are tending."* Huxley, Tyndall and others engaged in terrific controversies, Science and Religion very unfortunately and quite unnecessarily got ranged for a time on opposite sides: to some the fight was a grim reality: to all it was interesting. At a famous biological discussion a well known cleric, himself a distinguished man of science, when asked to intervene replied "My profession is one of peace, my advice is, let them fight."

Hitherto scientific investigation had been carried out mainly by two groups of people. University Professors early recognised that the highest teaching could be given only by those who are themselves adding to knowledge, therefore they combined research and teaching. The second group was very interesting; it consisted of men of private means, such as Cavendish in the 18th

* Relations of Man to the lower animals, in *Man's Place in Nature*, 1863.

Century, Darwin, Lawes, Earl Rosse, Lord Rayleigh, Lubbock, Sir John Evans, Pickering and others in the 19th Century who devoted their leisure or it might be their whole time to the study of science because they loved it: men to whom no labour was too hard, no trouble too great. To them the search for truth was the search for beauty, and in seeking for it they found their best means of self expression: they were true artists working in the spirit of the artist.

Apart from the few University Professorships and a few special appointments, such as the Astronomer Royal and the Directorship of Kew Gardens, Science was then in the position that poetry always has been in and still is in. Men could practise it only if they had other resources. "The poor poet" as Sir Arthur Quiller Couch reminds us, "has not in these days, nor has had for two hundred years, a dog's chance." The poor scientific worker then had no chance.

Gradually however as scientific investigation developed the demand for trained men developed. There sprang up a new profession, the scientific research worker. The pioneers had often worked under difficult and trying conditions: the first Rothamsted laboratory was a barn: the first chemical and physical laboratories at the Universities would now be regarded as deplorable. Pioneering work can be and frequently has been done under these conditions. But after the pioneer comes the detailed exploration and development and this needs elaborate equipment: the best that can be got. So the research laboratory and the research institution have grown up. This movement has gathered great force since the War: it is one of the most characteristic features of our time.

The advent of the Scientific Institution has greatly widened the scope of science by permitting and encouraging the application of science to technical and industrial problems. So long as science was confined to the Uni-

versities technical applications were necessarily restricted. A large firm might engage a few research chemists, and they often did remarkably well; where, however, an army is needed two or three could hardly be expected to make much impression. Very large business organisations such as Imperial Chemical Industries, the General Electric Company, Messrs Lyons, still have their own research staffs, men whom their scientific colleagues respect for their abilities and envy for their resources. But for general purposes the research institute is better and of these there are now many. The Institute of Brewing, the Millers, the Confectionery Trades, to name only a few, all have their research organisations financed by the industries concerned, sometimes with Government support. Agriculture is provided for somewhat differently: the Ministry of Agriculture has set up institutes at various centres: crop production and plant diseases at Rothamsted, plant breeding at Cambridge and Aberystwyth, animal nutrition at Cambridge and Aberdeen, dairying at Reading, fruit production at East Malling and Long Ashton; these are supported mainly from Government and partly from other sources. The amateur working like an artist without pay and simply for joy in the work has gone: a new type of professional scientific investigator has begun to develop, attracted usually by interest in the subject but sometimes only by the hope of getting a living. Both men and women are engaged: some of the women felt drawn to the work, some were influenced by two negative reasons: they did not want to stay at home and they did not want to teach so they tried research. The principle of equal pay for women and for men was soon conceded, though so far none of the higher posts has been given to a woman. Probably in no profession was there less difficulty about woman's entry: all classes of directors accepted them: those who hold with Greg that "the essentials of a woman's being are that they are supported by and they

minister to men'' thought it would be quite useful to have a woman in the laboratory to make tea for them in the afternoons and to tidy up after them: while those who hold with Virginia Woolf that it needs only a succession of women with £500 a year and a room of their own— independent, and with no arm to cling to—to produce something quite new in the history of intellectual progress, hoped that their institutes would share in the glory when it came though they did not offer £500 a year. Finally those (and I frankly confess myself one of this group) who are not specially interested in feminism but rather like womenfolk as human beings and see no reason why they should not work in the laboratories if they so desire and if they equip themselves for the purpose, were very glad to have them because they undoubtedly make for smooth working and they can do some things much better than men though on the other hand other things they do not do so well. How things have changed! Dorothy Osborne in a charming letter written in the middle of the 17th century expressed her astonishment at the very thought of a woman writing a book: "Sure the poore woman is a little distracted, shee could never bee soe ridiculous else as to venture at writeing books." What would she have thought of women's scientific papers now?

The change in character of the workers has naturally altered the character of the work. It has lost much of its artistry, and become very professional. It has become extremely specialised, and individual workers, being professional and not amateurs, rarely interest themselves greatly in the work of others however enthusiastic they may be about their own. New ideas and new things necessitate new words: but appalling hybrids are sometimes introduced: Balzac cynically remarks that "the advantage of science is that if you cannot make great discoveries you can at least make up new names." Worse still, the giving of a name is often taken as an

explanation of a phenomenon: this of course is an old complaint: Dean Swift tells how "professors," by dismissing all puzzling phenomena as "*lusus Naturae*, ... have invented this wonderful solution of all difficulties, to the unspeakable advancement of human knowledge." With some brilliant exceptions, scientific papers rarely make attractive reading, often they are dull and terribly prolix, lacking both style and dignity; sometimes the English is execrable, for the modern honours degree courses at the Universities have pretty well succeeded in eliminating that general education called by the rather priggish name of culture. In the main the papers are intelligible to the few other specialists in the same field, but they make and they are intended to make no appeal to a wider circle. Even the professional scientific workers reading some of the papers feel disposed to judge them as Chekov once judged a contemporary production: "It's not bad, but one might write a thousand such papers and things would not be one step forwarder, and it would still remain unintelligible why such papers are ever written." Few of the scientific journals pay their way, most are subsidised by their supporters through the societies which control them. The authors receive no pay and no royalties, on the contrary they usually as subscribers to the society help pay for publication: a great change from the days when Johnson could say: "No man but a blockhead ever wrote except for money."

Controversies have ceased: for professionals do not controvert, and in any case the problems are so specialised and the number of people interested so few that the protagonists would never get an audience even if they felt disposed to fight. No longer can truth be advanced by the clash of opinion, the laying together of many varieties of error. All that has gone, Huxley, Tyndall, Russell, Wallace, Liebig, if they could come back, would think modern science insufferably dull.

There are, however, some compensating new charac-

teristics. Scientific exploration is now much more detailed, much more thorough than it used to be. The amateur's interest burns high for a time, then it dies down. The professional is not subject to such fluctuations. It is immaterial to him whether he spend a month or a year on a problem: he can make sure of his decimal points. Further, as a specialist he recognises the need for organised exploration. In sharp contradistinction to the artist he is not seeking to express his personality in his work: he is indeed repressing his personality so as to become more completely and dispassionately receptive of the phenomena he is studying. He is therefore, unlike the artist, quite prepared to subordinate himself to the whole investigation. A new class of scientific workers have therefore emerged: the organisers or directors of investigation: men who can envisage the problem as a whole, can divide it into parts and allocate the several parts to the appropriate specialists. They succeed not by being brilliant investigators themselves, but by understanding how to bring together and keep together a good team of workers and how to develop a set of conditions favourable to their optimum activity.

A team of workers, carefully chosen, working together under competent leadership, can accomplish an amazing amount of work. Its advance is irresistible. The various workers in the team are kept informed of the whole position by means of carefully arranged conferences frequently dignified by the names "symposia" or "colloquia." At Rothamsted our staff of 60 scientific workers meets fortnightly during the session: at each meeting one or more members of the Staff give accounts of the progress achieved in a particular direction. In this way the advantages of specialisation are retained and the disadvantages—the isolation, the absence of the understanding and discriminating critic—are mitigated. The mathematician finds that he can help the

bacteriologist: the chemist is shown that the difficulty confronting him can be met by the mycologist or microbiologist. The more active scientific societies and the British Association arrange a number of such conferences on a large scale.

Perhaps the greatest advance so far made as the result of this team work has been the introduction of mathematics, thus permitting statistical control of biological experiments. The chemist and physicist can faithfully reproduce all the conditions of their experiments and so can obtain very nearly the same results in successive experiments, and the experiments themselves are steadily becoming more and more completely self performing and self recording: the failings and vagaries of the human machine are being more and more eliminated and the errors of the apparatus are steadily being reduced.

The biologist however, and still more the agriculturist, can never completely reproduce all the conditions of the experiments, because no two organisms are ever quite alike, and for the field worker, no two seasons are ever alike. It is therefore always possible that the differences observed are due, not to the factor varied in the experiment, but to differences in organisms supposed to be alike, or, in the case of field experiments, differences in soils supposed to be similar or differences in reaction to different weather conditions. When a biological or field experiment is designed in discussion with an expert statistician it is usually possible to calculate the odds that the result is due to the treatment and not to some chance or unpremeditated effect. All our modern experiments at Rothamsted are so designed, and the field experiments, which in the past have been the most difficult of all to interpret properly, have gained enormously in consequence. They can now be sifted much more rigorously than before: a result is not accepted unless the odds are at least 20 to 1 against it being acciden-

tal. Relationships can be traced between the experimental results and such weather conditions as rainfall, temperature, hours of sunshine. More interesting still, it is becoming possible to predict results of field experiments from a knowledge of the treatment and the climatic conditions: recently at Rothamsted some remarkably close predictions were made of the nitrogen content of barley grain reaped in July or August, basing the calculations on data completely assembled by the end of June.

These predictions have the great scientific interest that they help to complete the balance sheets of our experiments: if ever they come out correct it will show that all the factors are known and their relative importance has been accurately assessed: in the meantime they are never quite right and further search is therefore made for missing factors or for better expressions of their mutual relationships. Even slight discrepancies are followed up: they may furnish the clue to some important discovery. From the practical point of view the new methods have many advantages. They give quantitative expressions for the standard errors of different experiments and so they afford a long needed criterion of the relative values of different crops, fields and workers for experimental purposes. They open up the possibility, which may lead to results of incalculable value to agriculture, of constructing tables for the expectancy of crop yield on which a system of crop insurance could be based just as life insurance is based on the similar tables for the expectancy of human life.

Perhaps the greatest advantage of the team work, however, is that it affords the best way of breaking down the barriers unavoidably set up by the University division of science into "subjects" treated as if they were wholly distinct. It gives the workers a new breadth of outlook.

What will the end of it be? We may confidently expect the method of organised team work to add enor-

mously to the complexity of human knowledge. Our old landmarks have gone: the old simple generalisations, the conservation of energy, the indestructibility of matter, and a multitude of others have all broken down: even twice two is no longer four except in strictly comparable relationship to the space-time continuum. Science is becoming unspeakably difficult, and no one man can master even a single section of a single subject. We are further than ever from the intimate acquaintance with science that the older generation anticipated. Wordsworth would not now consider it worth while writing as he did in 1798: "The remotest discoveries of the chemist, the botanist or mineralogist, will be as proper subjects of the poet's art as any upon which he is now employed, if the time should ever come when these things shall be familiar to us, and the relations under which they are contemplated shall be manifestly and palpably material to us as enjoying and suffering beings." The old local scientific societies, the old natural philosophers long since gave up the unequal struggle: only the natural history societies remain and they will always have a chance of survival because the appeal of nature can never fade: men will always want to dig in their gardens and watch the friendly robin in their intervals of rest. New observations can always be made and will always be needed. But will modern science develop much further? or will it stop simply because it has reached the limits of the powers of the human intellect?

"There was the door to which I found no key,
There was the veil through which I could not see."

Will science follow the same course as painting, poetry and literature in the sense that it attains once in its history a high peak of perfection which it cannot hold and from which it moves afterwards to a different and a lower level? Will the high position now held by science be usurped by some other subject now either unknown or

else despised, just as science was in the ages of painting and of literature?

Whatever may be the fate of pure science it seems probable that applied science will in some form or other always continue. For applied science has the abiding human interest that it lightens the labour of man's hands, it renders the returns of his labour more secure, and ministers to his needs generally: "Planting trees of life in the garden of man's desire," to quote Robert Bridges. It is difficult to imagine human beings ever failing to cherish such an ally. But the very success of applied science raises some terribly difficult problems. Science which has given us such wonderful powers is utterly silent as to the right way to use them. Being able to do so very much we may yet, like Balzac's Man with the Talisman, achieve nothing. Every new advance renders more and more human labour unnecessary and throws more men out of employment: consumption cannot possibly keep pace with potential advances in production. Butler's Erewhonians might rise up to break the machines that did their work for them, as did our own people in the Luddite riots of 1811 and 1816, but there is no likelihood of any such thing happening now. What will the end be? We are back to the old problem put to us by all the old philosophers, clearly stated by Huxley in 1863 and not advanced one whit since his day: To what goal are we tending?

RECENT CHANGES IN THE SOURCES OF OUR FOOD SUPPLY.

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THE statistical basis for this paper is found in a series of Reports issued by the Ministry of Agriculture, the Empire Marketing Board and the Board of Trade, among which one of the most important is "The Food Supplies of Great Britain," issued in 1929 and supplemented by the volumes of statistics issued annually by the Ministry of Agriculture. The Empire Marketing Board Reports usually deal with individual groups of foodstuffs, and furnish a vast amount of information not easily obtained elsewhere. The Board of Trade returns give the full statistics, but, like all other statistics, they have to be read exceedingly carefully, including the footnotes, and deductions have to be carefully pondered before they are accepted. I have collected the material and discussed it at some length in a recent book, "The Farm and the Nation," published by Allen and Unwin.

An important fact that emerges is that the staple diet of the average Englishman changes but little. In the 20 years that elapsed between 1907 and 1927—perhaps the most momentous 20 years in

TABLE I.
AVERAGE FOOD SUPPLIES PER HEAD OF POPULATION. GREAT BRITAIN.

	Pre-War (1907).	Post-War (Av. 1924-25 to 1927-28).
	lb.	lb.
Wheat Flour	208	207
Meat	144.9	147.1
Beef and Veal.....	69.4	71.4
Pigmeat and Lard	42.8	46.8
Mutton and Lamb	28.4	26.2
Fish	43.7	41.9
Poultry	3.9	3.7
*Eggs (number)	111	116
Milk: Fresh (gallons)	19.5	20
Condensed and Powder. lb.	—	8.1
Butter	15.8	15.4
Cheese	8.7	9.5
Margarine	5.0	12.4
Potatoes	189	192
Fruit and Nuts (all kinds)	74	101
Sugar.....	80	86
Cocoa	1.1	2.6

* In shell only.

CHANGES IN SOURCES OF FOOD SUPPLY.

our history—the Englishman's food remained almost unchanged. The differences in the recorded values are so small that they almost certainly fall within the error of estimation. Such small differences as appear are in the direction of greater variety; the only marked changes are that we now consume more margarine, more fruit and more sugar than we did; these represent additions to our food supplies and not displacements of other foods.

There have, however, been marked changes in the sources of supply. The facts are collected and set out in Fig. I. We shall now consider the separate foods.

Proportions of Great Britain's Food supplies from various sources

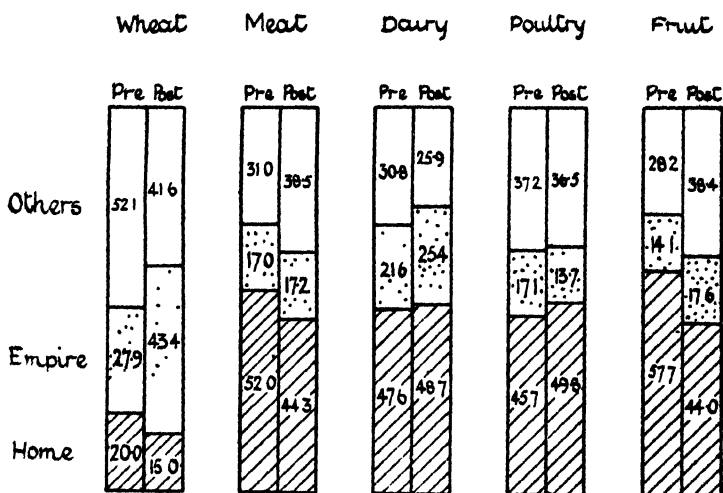


FIG. 1.

Wheat. An interesting change has occurred in the distribution of wheat during the past 40 years and it is still going on. Sixty years ago each region aimed at being nearly self-supporting. There was, of course, a considerable importation of wheat, but there was a large home production, and in consequence much wheat was grown in conditions to which it was not quite suited. Wheat is adapted to somewhat dry conditions and it suffers in this country in wet seasons. The movements of population in the last 50 years have been largely from the moist regions of the world to the dry regions, from the damp North-west Europe to the relatively dry regions of the United States, Canada and Australia, an interesting reversal of all previous movements of mankind which had, on the whole, been from the dry

regions of parts of Asia to the wetter parts of Europe. The return to the dry regions was accompanied by a return to the ancient products of husbandry. The cultivators of Mesopotamia had discovered that the three things doing best in dry conditions are wheat, barley and sheep, and the code of Hammurabi, drawn up about 4,200 years ago, but no doubt embodying much older rules, contains laws governing the grazing of sheep and the growing of corn. So to this day the chief products of the dry parts of Australia are wool and wheat; of South Africa are wool and maize. Canada and the United States both produce wheat in the dry parts, though not wool; it would be interesting to discover how they came to break away from ancient practice.

The reversion to the old husbandry products meant rather more than appears at first sight, for in the 2,000 years of farming under the moist conditions of the British Islands our farmers had gradually selected and bred from strains of cereals and of animals specially

TABLE II.

¹CHIEF WHEAT IMPORTS INCLUDING WHEAT MEAL AND FLOUR.

Million cwt.			
	1907.	1931.	1932.
United States	33.6	² Canada	35.0 .. 52.4
Argentina	22.0	Soviet Union	28.9 .. 3.3
East Indies (British) ..	18.3	Australia	26.9 .. 28.1
Canada	15.0	Argentina	21.7 .. 21.2
Russia	10.9	³ United States	11.8* .. 5.3
Australia	8.5	British India	0.5 .. 0.0
Other supplies	7.3	Other supplies	9.5 .. 7.2
	115.6		134.3 117.5
		U.S.S.R.	U.S.A.
1930.....		18.7	25.2
1932.....		3.3	5.3

*14.1 in Returns, but 2.3 of this was from Canada.

¹Imports of wheat meal and flour have been converted into wheat; 100 parts of wheat yield 72 of flour.

²The 1931 figures for Canada and the United States represent the origin of the wheat and not simply the port of shipment. The Trade and Navigation Returns show 32.5 from Canada and 14.1 from the United States, but some of the Canadian wheat is shipped from United States ports, and therefore entered as from the United States. The figures have therefore been corrected to 35.0 from Canada and 11.8 from the United States. No correction is available for the 1932 figures.

A special analysis by the Board of Trade showed that the details of the grain shipments were:—

	Country of consignment. Million cwt.	Country of origin. Million cwt.
From United States of America.	11.2	8.9
„ Canada	27.1	29.6

suited to our moist conditions. When these crops and animals were taken to the dry regions they naturally were not very successful, and the early records of the settlers are chronicles of much loss, hardship and suffering. Gradually, however, the art of plant breeding developed into a science, and varieties of wheat were produced suited to the prairies of Canada and the United States and the dry parts of Australia. The problems differed rather in the different regions. The chance discovery of Red Fife wheat solved the problem for the southern part of the Canadian prairies, but not for the northern parts where the summer is short. Here, therefore, the plant breeder aimed at rapidity of growth; instead of allowing 120 days from sowing to harvest (as he could in the southern prairies) he aimed at 100 only, and with each new sort was able to push the wheat belt further and further north. The variety called Marquis was the first great discovery; it allowed a considerable increase in the wheat area, and a more recent sort, Reward, allows still further extension.

In Australia the problem was to find drought-resistant wheat so as to push the wheat belt further and further inland; this quest has already been successful and it is still being pursued. There still remained the mechanical difficulty of cultivating the ground and harvesting the crop in somewhat dry regions where population is necessarily rather sparse; this was overcome by the invention of labour-saving machinery. The result has been an enormous increase in the wheat output from Canada and Australia (Table II). The same physical conditions apply in Russia and the United States, and equally marked increases might have been obtained there too. Owing to frontier changes direct comparisons are not easy in Russia, and in any case Russian supplies were always liable to vary from year to year. This is still true, in three successive years the imports from Russia have been:—

1930	18.7 million cwt.
1931	28.9 " "
1932	3.3 " "

How far this is due to climatic and how far to political factors we need not now consider. The United States is steadily dropping out as a supplier of wheat, and the import is less than appears because the figures quoted include also Canadian wheat shipped from United States ports; the reasons are probably financial. The enormous increase in wheat production in Canada and Australia, and the still greater increase in wheat-producing power, makes wheat-growing everywhere a very speculative business, and farmers who can grow alternative crops do so. Finally, when Great Britain went off the gold standard the price of wheat in our markets fell to a like extent and the American farmer still on the gold standard could no longer afford to send his wheat here. So great, however, is the productive power of Canada, Australia and the Argentine—to say nothing of our own—that further shrinkage of United States wheat would not affect us even if Russia fell out.

Beef. The changes in source of supply are shown in Table III. The most marked has been the enormous expansion in supplies from

TABLE III.
CHIEF BEEF IMPORTS.
All kinds including Tinned.
Million cwt.

	1907.		1931.	1932.
Argentina	2.73	Argentina	9.39	9.05
U.S.A.	2.60	Australia.....	1.14	0.96
New Zealand	0.40	Uruguay	1.01	0.70
Australia.....	0.15	Brazil	0.60	0.50
Uruguay	0.07	New Zealand	0.38	0.60
Other supplies	0.09	Other supplies	0.54	0.41
	6.04		13.06	12.22

Argentina and Uruguay. The chief reason has been the great improvement in refrigeration and in transport. This region of South America is climatically remarkably well suited to the growth of fodder plants, grasses and especially lucerne; it is also, on the whole, healthy for animals. The result is that the animals have food all the year round, they can be out of doors with little or no attention, and so they produce beef cheaply; the cost has been estimated at about 20s. per cwt. all the year round as against English costs of 30s. per cwt. in summer on the "extensive" system, and 75s. in winter on the "intensive" system. Further, the chilling process is so well developed that the quality of the meat is preserved during the 21-day steamer journey and the meat is delivered in good condition to the consumers in this country.

There are considerable areas in Australia where beef production would be possible. In the south, however, it has not developed because to be done cheaply it must be done extensively, and the Australian farmer finds the more intensive and laborious dairy farming more lucrative. So, of course, would the Argentine farmer if ever he settled down to the labour of it and if the population grew so much as to necessitate close settlement. In many parts of Australia, however, and especially in parts of Queensland and the Northern Territories, close settlement has not yet become necessary, and the conditions are not suited to the large scale handling of milk, so beef production has developed. The difficulty of transport is not yet solved; the present chilling process is not effective over the five weeks' journey and the meat has to be frozen, which impairs its quality. So long as this difficulty remains, development will be handicapped; I am not able to say what prospects there may be of overcoming it.

The other notable feature about the Table is the disappearance of the United States as a source of beef. This is partly the result of greater consumption in the United States—where, as here, much more beef is eaten than of any other sort of meat—partly also it results

from financial factors. Should the world ever require more beef than existing sources can supply, the greatest potential source is Africa. Here there are considerable regions of bush- and park-like country where cattle could be raised, subject to the difficulty of the dry season, which could often be got round; two serious but not insuperable difficulties are disease control and transport. If these were overcome two problems would still remain: the improvement of the grazing lands, which is now being investigated in the various regions of Africa with considerable hope of a successful issue, and the improvement of the animals, which cannot usefully be undertaken till a better environment is provided.

Mutton. In regard to mutton there has been no great change in source of supply since pre-war days. New Zealand still easily heads the list, sending practically half of all that comes from overseas. Australia is pushing ahead and has increased her contribution, but nothing yet appears likely to threaten New Zealand's supremacy.

TABLE IV.
CHIEF MUTTON IMPORTS.
Million cwt.

	1907.		1931.	1932.
New Zealand	2.02	New Zealand	3.47	3.92
Argentina	1.41	Argentina	1.55	1.38
Australia	0.88	Australia	1.53	1.16
Netherlands	0.22	Uruguay	0.28	0.16
Uruguay	0.05	Other supplies	0.46	0.53
Other supplies	0.04			
	4.62		7.29	7.15

The production of mutton must not be confused with that of wool; the same animal produces both in this country, but not in the semi-arid regions of Australia and South Africa that contribute so much to the wool supplies of the world. The Merino sheep is here the great wool-producer; it tolerates dryness better than any other domesticated animal, and it yields wool of excellent quality, but its mutton is much too poor to find a place in the world market. Good quality lamb and mutton are obtainable only from the types of animals that require moister, cooler climate conditions.

TABLE V.
CHIEF LAMB IMPORTS
Million cwt.

	1907.		1931.	1932.
United States	2.28	Denmark	7.34	7.67
Denmark	1.81	Poland	1.08	1.14
Canada	1.20	Netherlands	1.00	.97
Russia	0.05	Sweden	0.58	.43
Other supplies	0.08	Lithuania	0.36	.34*
	5.42	Other supplies	0.78	.85
			11.14	11.40

*Only from Jan./Aug., 1932.

Bacon. The imports of bacon have enormously increased, but the sources have changed ; the United States, formerly our chief supplier, has practically ceased to count, while Denmark, which came second on the list, is now a long way first, sending two-thirds of all our imported supply. Another and interesting new feature is the emergence of Poland as an important supplier of bacon ; Lithuania is also a new entrant into the market.

Dairy Produce. The changes in source of supply of butter and of cheese have been only small, but the changes in output of some of the countries have been very great. For butter Denmark still heads

TABLE VI.
CHIEF IMPORTS OF CHEESE.
Million cwt.

	1907.		1931.		1932.
Canada	1.70	New Zealand	1.73		1.85
Netherlands	0.24	Canada	0.71		0.75
New Zealand	0.19	Netherlands	0.17		0.17
United States	0.11	Italy	0.13		0.11
Other supplies	0.126	Other supplies	0.15		0.13
	2.366		2.89		3.01

TABLE VIA.
CHIEF IMPORTS OF BUTTER.
Million cwt.

	1907		1931		1932.
Denmark	1.82	Denmark	2.47		2.58
Russia	0.66	New Zealand	1.93		2.19
Australia	0.60	Australia	1.56		1.82
New Zealand	0.31	Finland	0.25		0.22
France	0.28	Argentina	0.37		0.39
Sweden	0.23	Sweden	0.21		0.18
Netherlands	0.17	Russia	0.40		0.32
Other supplies	0.14	Other supplies	0.86		0.74
	4.21		8.05		8.45

the list and Russia has fallen off considerably relative to other countries, though not in absolute amount, especially when allowance is made for frontier changes. The second place is now being taken by New Zealand whose output has been vastly increased. Cheese-making is so completely different from butter-making, that it is not surprising to find wide differences in sources of supply. Denmark, head of the butter list, sends us no cheese, New Zealand is unique in sending us large quantities of both, though less cheese than butter. The difference becomes more marked when the quantities are expressed in terms of milk used in the manufacture ; 1 lb. of cheese requires about 1 gallon of milk, while 1 lb. of butter requires about 2½ gallons. Canada has lost ground and the United States disappears from the list of supplies. Italy has come in and further changes may be expected.

Eggs. In pre-war days the sources of supply were restricted by transport, but this limitation is fast being overcome and we may in future obtain supplies from very distant lands. Already China sends

TABLE VII.
SOURCES OF SUPPLY OF EGGS.

	1907.	Millions.	1931.	1932.
Russia	861.5	Denmark	906	.. 768
Denmark	456.0	Netherlands	400	.. 168
Germany	338.5	Poland	322	.. 126
Belgium	256.0	Belgium	249	.. 190
France	147.8	China	180	.. 102
Other supplies	168.1	Other supplies	994	.. 944
	2,227.9		3,111	2,298

a respectable quantity. Denmark heads the list, having ousted Russia completely. Germany and France disappear as important sources of supply. Poland is apparently, but not really, a new source; in pre-war days Polish eggs were entered as German or Russian.

These last three items, bacon, dairy produce and eggs are linked together in the various husbandry systems and they may therefore be discussed together. The most striking feature of the Tables is the enormous importation from New Zealand of butter and cheese, from Denmark of bacon, butter and eggs, and on a smaller scale from Poland of bacon and eggs. It is further interesting that bacon and eggs are as inseparable on the farm as on the breakfast table.

Why have these specialised developments occurred? It is partly because of suitable natural conditions, partly through economic pressure. New Zealand has in its plains and valleys all the requisites of a good dairy country; a mild equable climate, sufficiently moist and free from cold to permit of the animals being out on grass practically all the year, and therefore producing milk at the least possible cost. It has, further, a sufficient supply of good water to satisfy all the needs of the animals, and an intelligent population sufficiently closely packed on the land to ensure adequate attention to the animals. It is, in short, in the dairy regions, a small farmers' country; and the small farmers are intelligent enough to work for a common end, and so competent that they can produce high quality commodities at low prices. Man for man the English farmer could hold his own against them, but the English winter is much more rigorous than that in New Zealand, and necessitates housing the animals indoors, a very costly proceeding. It is, therefore, highly improbable that we could ever produce butter as cheaply as can be done in New Zealand.

The uplands of the North Island are particularly well suited to sheep, and wool still remains one of New Zealand's major exports. The plains on the South Island are well suited to lamb-production.

Denmark was early forced by economic pressure into the combination of butter, bacon and eggs. Growth of population compelled closer settlement on the land and the replacement of extensive forms of husbandry by intensive forms suitable for small holdings. The dairy cow, the pig, and the hen are all essentially small farmers' animals ; they need and they repay close attention ; they are not, like the meat-producing bullock or sheep, adapted to sparsely settled conditions.*

When the Danish enterprise began some 70 years ago, transport limitations gave them a great advantage in our markets ; they used their advantage well and built up an admirable system of farm- and factory-production and of distribution in our country. By exceedingly hard work on the farms, in which the whole family, down to even small children, participates, by intelligent management in the butter and bacon factories, by co-operation to avoid wasteful overlapping, most of all by an admirable system of rural education, they have succeeded in building up a great industry and overcoming the handicap which their rather hard winters would otherwise put on their butter-making industry. We may certainly expect Denmark to retain its premier position.

Poland has considerable areas of land suitable to intensive settlement and the peasants have the basis of intelligence on which a good system of agricultural education can be built up. Since their liberation and re-establishment as an independent kingdom the Polish people have already made great advances in agriculture, and, if only they can retain their independence and be preserved from another " partition," the world will gain greatly by the contribution they can make to our common civilisation. During my visit in 1930 I was much impressed with Poland : with the peasants working in the fields and singing as they worked, expressing themselves in arts and crafts which reveal a considerable sense of colour and design ; with their politeness to the stranger, shown in the children's greeting " All honour to the name of Christ " whereupon one takes off one's hat and replies " For ever and ever, amen " : but this is not a paper on Poland. Bacon and eggs, the typical products of the skilful and intelligent small holder, certainly can be produced here, and either butter or cheese, if the difficulty of the cold winter can be met by skilful management as it has been in Denmark where, however, the problem is less severe.

Fruit. A remarkable change has taken place in our demands for fruit and this has led to corresponding changes in the sources of supply. The average consumption per head has increased nearly 50 per cent (Table I.), and three fruits have emerged as being *par excellence* the choice of the Englishman ; apples, oranges and bananas. Apples have the unique distinction of being the one important food that comes largely from the United States ; practically half our total

* Lamb production requires closer settlement than mutton production.

TABLE VIII.
CHIEF IMPORTS OF FRUITS.

1.—APPLES.

Million cwt.

1907.	1931.
Canada	United States
United States	Canada
Australia	Australia
Belgium	France
Portugal	New Zealand
Other supplies	Other supplies
3.52	7.59

2.—BANANAS.

Million bunches.

1907.	1931.
Costa Rica	West Indies
Canary Island	Honduras
West Indies	Columbia
Other supplies	Costa Rica
6.22	Brazil
	Canary Island
	Other supplies
	16.16

3.—ORANGES.

Million cwt.

1907.	1931.
Spain	Spain
Italy	Palestine
West Indies, British	Brazil
Other supplies	South Africa
6.121	Other supplies
	10.397

imports are from thence; then follow Canada and Australia. The two new sources of supply are France and New Zealand, and, personally, I should not be surprised to see much more coming from New Zealand in the near future, for large tracts of land are suitable to apple-growing, especially in the northern part of the south island and doubtless also the southern part of the north island. The change in sources of supply of bananas affords one of the most interesting examples of what can be done by deliberate scientific endeavour. Formerly the West Indies depended on cane sugar, but this industry was killed by subsidised beet sugar from the Continent. Experiments were started on other crops, and it soon appeared that bananas could be grown exceedingly well. Enterprising shippers provided the necessary transport conditions and now great quantities are grown annually.

The marked development of the Palestine orange industry is a high tribute alike to those Arabs who are growers and to the Jewish colonists who, under the *pax Britannica* resulting from the Mandate,

have been able to settle in the country and plant extensive new groves. Palestine has secured, and seems likely to retain, the monopoly of Jaffa oranges, and even larger supplies may be anticipated in the future.

The growing of oranges in Brazil, South Africa and Australia, represents a new idea in the feeding of Great Britain. Hitherto we have been content to receive fruits in their season. Modern developments of refrigerator transport, however, have allowed fruit importers to play off the Northern hemisphere against the Southern and so to ensure continuous supplies all round the year. The most striking developments have been with oranges. Up till the War oranges were entirely winter fruit, and Spain had almost a monopoly of supply. Transport developments, however, brought the Southern hemisphere into action, and now large quantities come from Brazil and South Africa and still further developments are planned. These are summer oranges ; they do not compete with Spanish oranges nor do they adversely affect British summer fruits ; they represent a new item in our diet. To have effected a change in something as unchangeable as the food of the average Englishman is surely a great triumph for modern science.

BOOKS AND THE FARMER

By

SIR E. JOHN RUSSELL, D.Sc., F.R.S.

Director of Rothamsted Experimental Station

AN ADDRESS DELIVERED AT THE
TENTH ANNUAL CONFERENCE OF
THE ASSOCIATION OF SPECIAL
LIBRARIES AND INFORMATION
BUREAUX AT WILLS HALL, BRISTOL



PUBLISHED BY THE ASSOCIATION OF SPECIAL LIBRARIES
AND INFORMATION BUREAUX

16, RUSSELL SQUARE, LONDON, W.C.1

1933

Books and the Farmer.

By SIR E. JOHN RUSSELL, D.Sc., F.R.S.

We are indeed fortunate to-day in meeting in this great City of Bristol—great not only by reason of its material wealth, but much more by its richness of historic associations, the courage and zeal of its early travellers and seafarers, and the high faith and enterprise of those far-sighted founders and patrons of its great homes of piety and learning : its Cathedral, its old public school, its grammar schools and secondary schools, and of more immediate interest to us, its University, the proud possessor of one of the most beautiful modern buildings in our land. And although Bristol is a large city and most of its citizens are necessarily urban in their outlook, and although most members of my audience are probably associated with town and city libraries, I do not feel that any apology is necessary for the subject I have chosen. There is no need for me to remind you of the importance of British agriculture. It is the third largest employer of labour in the country : it is fourth in order of productiveness, contributing about ten per cent. of the whole of our national output, and it occupies much more of our land than all other industries put together. The present time, moreover, is of special significance for agriculture : it is undergoing profound changes, almost a revolution. A long chapter of its history has just closed : a period that has lasted more than eighty years. It had opened in 1849 when the repeal of the Corn Laws threw our markets open to the whole world and so for the first time in our history exposed our farmers to serious competition from overseas—competition which at first had been stimulating but finally became devastating. The natural result of the removal of all trade barriers was the opening up of the great trade routes of the world so that we were able to buy wheat from Canada and Australia, beef from the Argentine, lamb and butter from New Zealand, eggs and bacon from Denmark and a host of other products from other countries.

After various trials and failures our farmers met the situation by producing only those things for which their land was best suited : they tended to become specialists. The methods would still have answered had free interchange of goods between one nation and another remained possible without the dumping that afterwards developed, but this was not so and changes had to be made. A new chapter opens this year with changes in marketing procedure and the institution of quotas and commissions, and our farmers once more hope for some degree of security of market. A greater change has been the attempt to organise the industry to ensure much more systematic production than we have hitherto had. Happily these changes come at a time when our farmers include many expert specialists able and willing to take advantage of the help that science and engineering can give them. They are not as yet great readers but that we hope will come, and here is where the help of the trained Librarian will be of profound importance.

There are two groups of readers coming within my title "farmer" for whom a library should cater : the expert adviser and the actual

tiller of the soil. On the whole it is easier, though perhaps more expensive, to cater for the expert than for the farmer. The expert knows what he wants: you can either supply it or you cannot. Expert treatises, however, have so short a life, and editions follow each other so quickly, that only the largest libraries can hope to keep up with them. Fortunately in agriculture some useful series of monographs have been published, and if these are kept up to date they supply the expert with the main outlines and put him in the way of obtaining the details. Two series of monographs should be in every library: the Ministry of Agriculture series, which are the cheapest of all, costing only a few shillings each*; and the Rothamsted series, dealing with agricultural science, costing rather more. These monographs give general accounts of the various aspects of agriculture and agricultural science and they furnish the expert with the references to books and journals from which the full details can be obtained. In addition certain government publications which are very inexpensive but of great value should be in all libraries that set out to help farmers and agricultural experts:

- (1) The Agricultural Statistics published annually by the Ministries or Boards of Agriculture for England and Wales, Scotland, Northern Ireland and the Irish Free State.
- (2) The Agricultural Output and the Food Supplies of Great Britain, 1929 (Ministry of Agriculture).
- (3) The Agricultural Output of England and Wales, 1925. This is one of the best accounts of English agricultural production that has yet appeared.
- (4) The Economic Series (Orange Reports) of the Ministry of Agriculture.
- (5) The Reports of the Empire Marketing Board: usually each deals with a particular group of commodities.
- (6) The Year Books of the Dominions.

These usually give the expert and the farmer all the information about farm products required for ordinary purposes. It is, however, necessary to warn the reader that he should study the footnotes to the tables and particularly observe the regions for which the statistics hold. There are so many pitfalls. The expression "the United Kingdom" changed its meaning on January 1st, 1922, when Southern Ireland became the Irish Free State and ceased to be included. Statistics before that date and after that date are therefore not directly comparable and some correction is needed. The Ministry of Agriculture and the Empire Marketing Board do not deal with the same region: the reports are perfectly clear, but the readers do not always take notice of the difference. The Ministry of Agriculture statistics refer only to England and Wales except in the summaries where they refer to Great Britain and the whole of Ireland, Irish Free State included. The Empire Marketing Board statistics on the other hand refer to the present United Kingdom including the Isle of Man and the Channel Islands but excluding the Irish Free State. The two sets of figures are therefore not comparable. Particular care is always needed in quoting statistics: personally I get mine checked by friendly

* The earlier issues were called Monographs; later ones are called Bulletins.

helpers at the Ministry of Agriculture or the Agricultural Economics Research Institute, Oxford, and, while one could hardly issue a general recommendation to this effect, readers should always be urged to discover precisely what the figures are intended to express.

It is a commonplace that no book ever gives quite the information one wants : the author always seems most obtusely to miss the one thing we wish to know about. Fortunately this difficulty has been largely overcome so far as the agricultural expert is concerned. Thanks to the strong line taken by the Imperial Agricultural Conference at Westminster in 1927, there are now established in this country eight agricultural bureaux the function of which is to supply information on subjects coming within their purview to any agricultural expert within the Empire. The prescribed channel of communication is through the official correspondent, but in practice a very liberal interpretation is put on this, and information is freely given to any *bona fide* enquirer. Certainly any enquiry from a librarian would receive full attention. The Bureaux are as follows :

<i>Subject</i>	<i>Name of Bureau</i>	<i>Address</i>
Soils, Fertilisers, and Crop Production.	Imperial Bureau of Soil Science. Director, Sir E. J. Russell.	Rothamsted Experimental Station, Harpenden.
Animal Health and Disease.	Imperial Bureau of Animal Health. Director, W. Horner Andrews, D.Sc.	Veterinary Laboratory, New Haw, Weybridge, Surrey
Animal Nutrition : Relation of Food to Disease.	Imperial Bureau of Animal Nutrition. Director, J. B. Orr, D.Sc., F.R.S.	The Reid Library, Rowett Institute, Bucksburn, Aberdeen.
Plant Breeding, especially Cereals.	Imperial Bureau of Plant Genetics. Director, Sir R. H. Biffen, F.R.S.	School of Agriculture, Cambridge.
Grasses and Forage Crops.	Imperial Bureau of Plant Genetics. Director, Prof. Stapledon.	Agricultural Buildings, Alexandra Rd., Aberystwyth.
Fruit Growing and Transport.	Imperial Bureau of Fruit Production. Director, R. G. Hatton, M.A.	East Malling Research Station, Kent.
Breeding of Animals, Genetics.	Imperial Bureau of Animal Genetics. Director, F. A. E. Crew, D.Sc.	King's Buildings, Edinburgh University.
Parasites of Animals.	Imperial Bureau of Agricultural Parasitology. Director, R. T. Leiper, D.Sc.	Winches Farm, Hatfield Rd., St. Albans.

If the enquiry obviously fits any of these Bureaux it should be sent straight in and it will be answered : if a book or journal has to be consulted by the enquirer the appropriate reference will be given and you will be told where the volume could be borrowed. You need have no hesitation whatever in approaching any of the Bureaux and if you are in doubt as to which is the appropriate one, send the enquiry to the Soil Bureau at Rothamsted and it will be passed on to the proper quarter. I cannot too strongly commend the Bureaux

to your notice : they have very efficient methods for collecting and transmitting information on their special subjects.

Fortunately there are now in operation various methods for borrowing books and journals which the library does not possess. The National Central Library and the Science Library, South Kensington, suffice for most ordinary purposes. Many of the special books and journals wanted by the agricultural expert can be borrowed from the library of the Ministry of Agriculture, Whitehall, merely on payment of postage : the procedure is perfectly simple : you write up to the secretary on official library paper and the book comes by return of post. If the Ministry does not possess the volume the Royal Agricultural Society may possess it and be willing to lend it. The borrowing of journals is more difficult than that of books. The World List of Scientific Periodicals* shows the library in which (if available at all) it can be found ; alternatively the National Central Library (Malet Place, London, W.C.1) or the Science Library may be able to locate it and even arrange for it to be borrowed. Journals, however, are often irreplaceable and therefore not sent out on loan : in that event there is nothing for it but to tell the would-be borrower where to go and furnish him, if necessary, with an introduction. Our position at Rothamsted is that we are prepared to lend through the National Central Library any book that could be replaced if lost but we do not lend journals or books that are now out of print. We are, however, always glad to receive students and enquirers in our library and give them all the help we can in finding their way through the extensive literature of agriculture and agricultural science.

This question of Journals is a growing difficulty with which I confess I see no way of dealing. It is far worse than the problem presented by books. Most of us can decline to buy books on the score that if the book is a good one it will go into a second edition and we can buy it then, while if it is bad or indifferent we don't want it anyway. But a journal is different. It is the most dreadful and insidious form of compulsory purchase ever invented. If you are induced to subscribe for one year you feel you must go on : an incomplete or broken set is revolting to all the best feelings of the true librarian ; so for years the parts pile up, occupying good shelf space and draining financial resources to pay for the indispensable binding. Before the War the numbers were manageable ; since the War they have risen enormously and they still continue to rise. At Rothamsted, though we set up to be only an agricultural library, we have to take over 600 journals and periodicals. But it ill befits me to grumble for I took an active part in starting yet another one last year.

The reason is, of course, the enormous increase in numbers of scientific workers all over the world. At present every one of them feels bound, if he wishes to get on in life, to publish at least one paper a year. Enthusiastic heads of departments feel that they must grind out papers corresponding in number to the size of the department. Most of them, in conformity with university regulations, publish the students' exercises that gained the M.Sc. or Ph.D. degrees. Some publish almost all of their note-books ; some do even more.

* A new edition is now in preparation and will, it is understood, appear shortly.

"I don't mind him publishing his note-books " said one scientist of a colleague, " what I do object to is his publishing his entire waste-paper-basket."

But there it is ! For the expert and the scientist this is the age of journals : and librarians are in the unfortunate position that a journal once taken must always be taken.

Of course the journals are not much read : they are received and entered up, particular papers are noted for possible future use ; one or two may even be read. But they cannot be ignored, and so the Abstract Journal has grown up : a journal which itself publishes no original work but only abstracts of what appears in other journals. Those necessary for the agricultural expert are :

Biological Abstracts (superseding Botanical Abstracts and Abstracts of Bacteriology). (U.S.A.)

British Chemical Abstracts.

Chemical Abstracts. (U.S.A.)

Experiment Station Record. (U.S.A.)

Zentralblatt für Bakteriologie.

Biedermann's Zentralblatt für Agrikulturchemie.

Proceedings of the International Society of Soil Science.

The abstracts, however, often appear much later than the original paper, and as an early source of information the Agricultural Index published by the H. W. Wilson Company, is useful ; it gives the titles of papers of agricultural interest appearing in current scientific journals.

Usually, the abstracts give the expert all the information he wants, but not always, and then he wishes to see the full paper. The reference may be to some journal unobtainable by the methods I have already described : perhaps some obscure journal the title of which is so abbreviated that even the language in which it is written is not recognisable. You need not despair, however ; the Agricultural Bureaux may still help you, for they have in addition to their regular supply of journals (which they cannot lend out) a large number of reprints of separate papers which they can lend, and they can often obtain others which they do not possess. By applying to the Bureau you may be able to borrow a reprint of the paper wanted even though the entire journal be unobtainable.

The Bureaux are able to give still further help. Before the War practically all the important papers and reports in science and agriculture were published in English, French, German, and Italian. If you could read these languages you could review most of the progress in agricultural science and practice. But since the War the wave of nationalism which has done so much to complicate trade, industry, and economic activity, has been at least as effective in complicating scientific work. Russia, which formerly produced few—though good—papers on agricultural science, now publishes more voluminously than any other country, and almost invariably in Russian. It is exceedingly difficult to keep the sets of periodicals complete, so numerous are they and so sudden in their appearances and disappearances ; as a further complication the numbering is not always consecutive and No. 5 may appear before No. 3. Yet the more important of them at any rate must be available to the

expert. If this were all it would simply add one more language to the list. But it is not all. Among the nations set free after the War are some very gifted agriculturists and scientific workers whose investigations cannot be ignored by an agricultural expert concerned with their particular subject. But with the liberation of the nations came also the liberation of their languages, which even the most ruthless oppressors never succeeded in stamping out. The use of their own language is for the people of these new nations a pious exercise which they most passionately and devotedly perform. Scientific workers in these newly liberated nations now publish in their own languages, and not, as before the War, in one of the great international languages. So an agricultural expert in this country, having obtained access to a paper he wants, may have the mortification of finding that it is published in a language which he not only cannot read but may not even be able to identify. The Rothamsted library now receives journals in twenty-four different languages, and still more are threatened. When some of my friends and colleagues in the Ukraine told me they were proposing to publish a new journal of agricultural science in their own language I retorted that we would flatly refuse to read it. Their reply was "We shall do such good work that you will have to read it." Our Armenian colleagues have gone a step further. They not only use their native language for their scientific papers but they have invented a new script in which to write it. The script is certainly attractive to look at ; it is not broken up into any recognisable letters but has the easy flow and rounded curves of Persian. I recently sent up an Armenian paper to our translating staff for a summary but it came back with the comment "We are sorry, but we don't read fret-work." The Poles, the Czechoslovakians, the Hungarians, the Rumanians, the Latvians, the Palestinian Jews are doing admirable work in agricultural science and practice but publishing it in their own language. Some of these languages had never in the past been used for science or indeed for any high intellectual activity : they contained no scientific terms ; sometimes not even a word to express so simple a notion as a "percentage." Quite undeterred by this difficulty the scientific workers have proceeded to make up new words to express modern scientific conceptions. I for one do not blame them : during the long years of oppression their language was the chief tie that kept them together ; children learnt it from their mothers, sometimes under difficulties and even threats of dire penalty. By a true instinct they knew that so long as they kept their language they had the key which would one day loosen their fetters*, and now that they have their liberty they are remaining faithful to the old mother tongue.

It is quite usual for these workers to add a summary in one of the three common languages, English, French, or German, but this usually whets one's curiosity rather than satisfies it. One obvious solution would be to publish all the papers not only in the native language but in one of the three others : this, however, is overruled at once by the insuperable objection that the cost of printing, already almost unbearable, would be doubled, and the space on the library shelves would be consumed at double the pace ; for when it comes to

* Quand un peuple tombe esclave, tant qu'il tient bien à sa langue, c'est comme s'il tenait la clef de sa prison.—(A. Daudet).

detailed discussions translations are not entirely valid evidence. The Bureaux meet the difficulty for all ordinary cases, as they are prepared to undertake or arrange for translations, and to furnish at very cheap rates photostat copies of tables, diagrams, or if need be the whole paper.

We turn now to books on agriculture : an immense number from which all but the largest libraries must make a strict selection. A specialised library will, of course, choose its own line, but there is a central core of books that should be possessed by all libraries intended to help the farmer and the agricultural expert.

The basis of the selection should be by countries, and within each country by historical periods ; within each period by subjects. The justification for this arrangement is that agriculture is far more intimately associated with the life of the people than any other industry : it dominates the whole of the activities of the countryside and the outlook of all who dwell there. It is impossible to dissociate the great movements in country life from the great changes in agriculture. Moreover the time element plays a determining part in agriculture : the processes are governed by Nature and not by man, and you cannot hurry Nature's pace nor speed up the cycle of the seasons. Seed time, harvest time, lambing time, all these are set by Nature : we can make only minor changes.

As the guide both to the history of farming and to its literature I put first on the list Lord Ernle's *British Farming Past and Present* : by far the most complete history of the British countryside yet published. Among the shorter histories Mrs. M. E. Seebohm's *Evolution of the English Farm* (1927) is one of the most readable ; being well annotated it is also a good guide for further study. Curtler's *Short History of English Agriculture* (1909) is another good book for the student.* But you should also try to secure a few of the old books themselves, for they give character and dignity to a library. For students' use good modern editions should be obtained where available.

Agriculture was one of the first arts to be practised but one of the last to be written about : the classical writers, excepting only Virgil, were content to extol it without descending to detailed description. But there were some good Roman writers on agriculture and you should secure translations of Varro and especially of Columella, for the Roman practices they describe passed into France and Flanders and thence some of them came to England. Throughout medieval times these *Re Rustica* writers, as they are generally called, were preserved, and they were in great favour when printing first began : the Rothamsted library possesses no fewer than twenty editions between the years 1472 and 1598, and this represents only a fraction of the output. The books were paraphrased at the end of the thirteenth century by Petrus Crescentius, a senator of Bologna ; his work was copied in the days of manuscripts and printed in 1471 at Augsburg by Schussler ; the first book on agriculture to be issued from any press. The Rothamsted library possesses a perfect copy, and it is not only the first but, to my mind, one of the most beautiful editions ever printed on agriculture. It was very popular and lived longer than any book since published : our library contains no fewer than twenty-six

* For books on the economics of the countryside the List of Studies in Economics and Political Science of the London School of Economics should be consulted.

editions between 1471 and 1805, many of them folios beautifully executed. Curiously enough no English edition ever appeared, but a three-volume edition was issued at Milan in 1805 and is still sometimes obtainable.

English writers on agriculture seem to have owed but little to the Roman writers or to Crescentius, but they, too, were slow in starting, and it was not till fifty-two years after Caxton set up his press that the first book on agriculture appeared here.* It was Fitz Herbert's *Boke of Husbandry* (1523, but the more usual edition is 1534), one of the raciest and most typically English text-books ever written. The Early English Text Society reprinted it some fifty years ago (1882) and this edition should be secured if possible. But the language is somewhat archaic and country readers may not easily follow it.

It was during Elizabeth's reign that agricultural writers first got really busy in England and these authors are quite easy to read, though, in general, they lack both the brilliancy and the dignity characteristic of their time. They could, however, hardly manage to be dull, and even the printers' announcements were impressive. I always like the colophon used by John Wight (1578) in Heresbach's *Four Bookes of Husbandry*. "Imprinted at London for John Wight, dwelling in Paules Church-yarde, at the great North doore of Paules." Then came a duller period under the first Stuarts: the Star Chamber imposed restrictions on printing and, till its abolition in 1641, few agricultural books were published excepting only reprints of Gervase Markham—a writer that we find tedious although his great popularity with his contemporaries is shown by the large number of editions through which his books passed, and the well-worn and thumbed condition of the volumes left over to us. Then came the civil wars of 1642 to 1649 when again few agricultural books were written. Immediately afterwards, however, with the more settled form of government the flow started, and it began with two writers, Blith and Hartlib, whose works can still often be found in second-hand bookshops and should be obtained if possible. Blith (*The English Improver*, 1649) was one of the first of the new improvers and Hartlib an enterprising person who published other people's manuscript or letters without revealing their names and so obtained a good deal of credit that was not properly his. If possible you should get his *Discourse of Husbandry* (1650)—a rather scarce little book, or better still and more easily obtainable, his *Legacie of Husbandry* (1651). Both were written by Sir Richard Weston, a royalist refugee in Flanders, who relates how he saw there such crops and such grass, "so good to feed all sorts of Cattel, as the best meadows in the Countrey do not yield the like," which set him reflecting "what an huge improvement I might make of my own Estate if God almighty pleased to permit me quietly to enioie it": unfortunately for British agriculture this was not to be. Again comes a period which is blank for the general reader, though interesting to the student because enclosure was gradually proceeding and the necessary agricultural changes were being worked out. The scholarly-minded lover of woods and gardens will enjoy John Evelyn's *Silva* (1664) which Arthur Doubleday and Co. recently reprinted in two attractive volumes. If possible you should get a Mortimer,

* Curiously enough, Walter of Henley's book, famous in the thirteenth and fourteenth centuries, was not printed till 1890.

his *Whole Art of Husbandry* (1707) is one of the classics of agricultural literature, and if you live near the Chilterns get William Ellis, *Chiltern and Vale Farming* (1733) or *The Modern Husbandman* (1731); but you should in any case try to obtain Jethro Tull, *Horse-hoeing Husbandry* (1731)—for choice get Cobbett's edition (1822 or 1829) because of the spicy preface: it gives a good picture of the farming outlook in those early eighteenth century days. The next fifty years produced little of direct agricultural interest: the patron still dominated literary effort and, during most of the eighteenth century, men with a gift for writing did not use their talent for agriculture.

There were, of course, diarists and letter writers, and one of these gives an excellent account of the details of daily life in the country: the Rev. James Woodforde's *Diary of a Country Parson*, 1758-1781 (Oxford University Press, 1924 onwards). Here are one or two typical entries: "Aug. 17th 1788. Begun shearing my Wheat this morning and gave the shearers according to the Norfolk custom as under: a good breakfast, at 11 o'clock plumb cakes with caraway seeds in them, and some liquor, a good dinner with plumb Puddings and at 4 Beer again . . . Will brewed this morning a barrel of Ale before he went shearing Wheat at 12 o'clock . . ."

Listen to this as a cure for ague—then very common in the countryside: "May 22nd 1779. My boy Jack had another touch of the Ague about noon. I gave him a dram of gin at the beginning of the fit and pushed him headlong into one of my Ponds and ordered him to bed immediately and he was better after it and had nothing of the cold fit after, but was very hot." To some farmer friends he gave this dinner: "Nov. 20th 1799. A fine Rump of Beef boiled, 4 fowls boiled and Bacon, a fine neck of Pork roasted, and quantities of plum puddings. Wine, Rum and Beer as much as they would. There was drunk 3 Bottles of Wine, of Rum 5 bottles. Sister Clarke and Nancy dined by themselves in the study."

Agriculture itself, however, made great strides from the middle of the century onwards. The experiments of Townshend and of Coke in Norfolk, and those of the Edinburgh Society in Scotland, provided a stimulus. The king himself was the great patron and before long Arthur Young was able to write: "The farming tribe is now made up of all ranks, from a duke to an apprentice." Once more agricultural writings were slow to appear, but towards the end of the eighteenth century the flood of writing began and has never since ceased. Among the early productions was one of the world's classics: Gilbert White's *Natural History of Selborne* (1789), of which you should have an attractive, well-illustrated edition so as to induce readers to take it. After this comes the spate. One of the great enterprises of the time was the survey by the Board of Agriculture, then first established, of the agriculture of Great Britain; this was done by counties and you should certainly have the survey of your own and, if possible, of your neighbouring counties. There were two editions: the early quartos (1793 and 1794) and the later octavos (1796-1813); on the whole the latter are more suitable and are also more easily obtained. The map, however, should be included: many copies have lost them. In this period comes Arthur Young, one of the greatest figures in agricultural literature, who could observe carefully and set down faithfully what he saw in crisp lucid English which

makes even his technical passages easy to read. Even on the shortest of lists of agricultural books he must find a place. Chief among his works are his travels in England and Wales : first in the south (1768), then in the north (1770), and then in the east (1771) ; afterwards to Ireland and France. All these have been recently reprinted in whole or in part so that copies are easily obtainable : the French tours by G. Bell and Sons, selections from the Irish tours by the Cambridge University Press, and the English tours by the London School of Economics. William Marshall belongs to this period, but is less interesting and would be included in the list only for local reasons, if at all.*

It is hardly necessary to delay over the nineteenth century agricultural writers : some of them possess considerable technical merit, but they do not come up to the standard of the nineteenth century farming. Agriculture suffers from the difficulty that its writers have usually been poor practitioners. Arthur Young is the outstanding example ; he is almost unequalled as an agricultural writer yet he failed when he tried himself to farm. He knew it : " My Mother," he says in his Autobiography, " proposed that I should take a farm. I had no more idea of farming than of physic or divinity. . . . And the circumstance which perhaps of all others in my life I most deeply regretted and considered as a sin of the blackest dye, was the publishing the result of my experience during those four years, (1763-1766) which, speaking as a farmer, was nothing but ignorance, folly, presumption, and rascality." (He is here referring to the *Farmer's Letters to the People of England*, 1767.) Two publications cover all that is usually wanted in regard to the nineteenth century : both are mines of valuable and interesting information : Morton's *Cyclopedia of Agriculture*, and the *Journal of the Royal Agricultural Society of England*.

About modern agricultural books it is difficult to speak because the subject has now followed the usual course and become highly specialised. First, and a long way first, I must put A. D. Hall's *Pilgrimage of British Farming* : a vivid picture of the farming of England written by one who, in our day, is unequalled as an observer and as a master of lucid and attractive English. It gives us a faithful account of the agriculture that is now passing away ; of the systems and methods in the stage of development they had reached before the War shook them so violently that it caused them all to totter and some to crash ; it is a record that will undoubtedly live long after many of our current books are forgotten. Two books are in a category by themselves : both are written by H. Rider Haggard, who, after acquiring immense fame for his books of adventure, turned farmer and wrote down his own experiences in *A Farmer's Year* (1899), and his impressions of British agriculture derived from personal visits in *Rural England* (1902). These volumes should certainly be obtained. As a reference work the twelve-volume *Cyclopedia of Agriculture* edited by R. Patrick Wright is still the most complete we have, though now nearly thirty years old. Messrs. Ballière, Tindall and Cox more recently published a good *Encyclopedia of Scientific Agriculture* edited by H. Hunter. A connected account of agricultural practice is given

* The London School of Economics has published a useful Bibliography of Travellers' Descriptions of England and Wales.

by J. A. S. Watson and J. A. Moore.* Four good books of reference on the British Islands are: H. J. Mackinder, *Britain and the British Seas* (1930); *Great Britain: Essays in Regional Geography* (1930); Dudley Stamp, *The British Isles: A Geographic and Economic Survey*; and the *Agricultural Atlas*, Malcolm Messer (Ordnance Survey). Whether you can possess these or not the little County Geographies of the Cambridge University Press should be obtained. Among periodicals the *Journal of the Ministry of Agriculture* should certainly be taken; also the reports and books issued from the Agricultural Economics Institute, Oxford, especially *The Future of Farming*, C. S. Orwin; and the publications of the Bureaux and the Experiment Stations. The Horace Plunkett Foundation issue some valuable reports on Co-operation. Other books worthy of consideration are: Viscount Astor and K. A. H. Murray, *Land and Life*; Lord Lymington, *Horn, Hoof, and Corn* (1932); Montague Fordham, *A Short History of English Rural Life* (1916); and C. Dampier-Whetham, *Politics and the Land* (1927).

For the rest the great difficulty is one of choice; I doubt if at any time in the world's history there were more books published on agriculture than now. The United States is the chief source of supply, and I marvel that they can all find a market; one is inclined to believe, with Pope, that—

“Where so much is said,
One half will never be believed,
The other never read.”

Most of the American works have, of course, little bearing on English farming, but one of Prof. Warren's more general books on United States agriculture (*The Agricultural Situation*, G. F. Warren and F. A. Pearson Wiley, 1924, or his *Farm Management*), would be an interesting and useful addition to our list.

Considering how much importance now attaches to Empire agriculture as a source of food for the Nation it is unfortunate that we have so few books dealing with it. I have given a general picture of it in my book *The Farm and the Nation*, but no more detailed account has yet appeared. The material can be got out from the official year-books, and something more vivid but less detailed is given in some of the travellers' books: I commend for example R. G. Stapledon, *A Tour in Australia and New Zealand: Grass Land and Other Studies* (1928). Duckham's *Animal Husbandry in the British Empire* (1933) deals with the live-stock side of the industry.

These various books would take a little time to collect, but they would not cost much and they would give the expert, the good farmer and the intelligent general reader a broad view of the subject and, at the same time, sufficient detail for all ordinary purposes.

I should, however, like to see the libraries go much further than this and endeavour to arouse among farmers themselves a taste for good reading. Perhaps this lies outside your province; it is, however, so important that I still feel justified in bringing it before you. There are certain difficulties. Farmers as a body do not belong to either of the present-day leisured classes: they have only little spare time, and that is in the evenings when the long day's work is done. They read the technical agricultural press which is now very good, and

* Watson and Moore. *Agriculture, The Science and Practice of British Farming.*

thanks to the devoted labours of the County Organisers and the Advisory Officers they are kept informed of modern developments in agricultural science and practice. But their active outdoor life, with the early morning start, is not conducive to serious reading of books in the evenings. In general, too, the farmer has little temptation to buy books. If you look round the bookshop in an ordinary market town you can easily walk out without buying anything. I have asked some of my publishing friends whether they could not make some joint effort to create a greater demand for books among agriculturists and other dwellers in the country, but the difficulties seem to be considerable. In farm-houses one is more likely to find books on agriculture of the period 1820 to 1870 than of 1900 to 1930. In the olden days some of the packmen carried books round and ensured some sort of distribution : now there is nothing of the kind. It is easier to buy a modern book on agriculture in Oxford Street than in a market town where farmers foregather weekly. Except where a school teacher vigorously encourages and stimulates it there is probably less reading of good books in farm-houses now than thirty years ago. In those days the *Pilgrim's Progress* was still widely read, and, more important still, many farmers began the day's work by the reading of a chapter from the Bible and of a prayer from the Daily Service. Considered simply as a daily exercise in good literature the procedure was good : it laid the foundation for the development of personality and power of shrewd comment that has always characterised the best men and women of the English countryside, whether landowners, farmers, or farm workers. Volumes could be filled with the expressions of the old generation of farm workers : I remember our first tractor once coming to a standstill in the field, and the old workers making scathing comments while the driver looked for the cause of the trouble and found a small insect in the carburettor : " Look ! " said one of them, aptly paraphrasing St. Paul, " how the weak things of the world do confound the things which are mighty ! " Unfortunately all this is passing : and instead we have the Sunday paper and the " talkie," which again considered simply as exercises in literature, form a poor exchange. There are, however, two new factors at work which may yet do much to bring good books into the farm-house and the farm worker's cottage : the wireless, which has already brought so much pleasure into country life ; and the County Library, the branches of which are often worked from the village school. Both teachers and scholars have told me how much the books are appreciated, especially in the remoter places where the winter evenings seem very long. There should be available three classes of books for circulation :

- (1) Good general literature, including fiction, travel, history, biography, science, poetry, and essays (these are not placed in order of merit though it may happen to be the order of general preference).
- (2) Good literature dealing with country life.
- (3) Technical and educational works such as I have already described.

Of the first group I shall say nothing except that a great responsibility lies upon the person making the selection because he or she can

foster or kill the taste for reading in many a country household. Country tastes are clean and robust: there is no room for the sickly, morbid, or prurient, and no appreciation of the oversubtle: but English literature happily contains vast stores of clean, healthy, vigorous writing that will stir the imagination and quicken new interests, so adding greatly to the richness of country life. But of the second group I must say something.

Literature dealing with country life ought, on the face of it, to be very popular among country readers. People are more interested in human beings than in anything else and the English countryside is perhaps unique in its wealth of good and almost unexplored material. The story of how the countryside was hewn out from the primeval forests, how the waters were confined and the pestilential swamps converted into rich farm land has the makings of an enthralling tale, but so far it has hardly been told as it deserves. The farm itself is rich in good material, yet only once has it been the subject of great literature and that was long before our time. Virgil's *Georgics* stand alone as the undying epic of the farm. The countryman can still read it with pleasure and marvel at the depth of understanding, the richness of language and the wealth of imagery that have caused this book to live through the ages and to be passed down lovingly from one generation to another as something to be prized and handed on: the possession not of one age but of all. It is available to all readers now, set out in stately, glowing English by Mackail.

But if there was only one Virgil, there have been many others nearer to or in our own time, writing faithfully, sometimes even caressingly of the things of which we know; who, seeing beyond the surface of things to the motive power behind, and reading the thoughts of men whose words are few, show us something that we had missed. No two people would make up the same short list, but there are a few names that can hardly be left out. First in order of time comes Tusser, the pre-Elizabethan poet or rhymester (whichever you prefer), who from Eton and Cambridge took to farming and failed, but left us some rhymes which for their rugged sanity have lived through this last 400 years, and two fine editions issued within the last three years show that they are still good for a long life yet. His *Five Hundred Points of Good Husbandry* should be on the shortest list.

Somewhat later comes an account by an adventurous spirit, Celia Fiennes, of a journey round England made on horseback in 1697 in which she describes the things she saw and the people she met. She went from her home in Wiltshire up to the border and even ventured into Scotland. But there she could not remain: "They live in so nasty a way, I rather chose to stay and see my horses eat their provender in the stable than to sit in ye roome for I could not bring myself to sit down nor to Eate any of the food they should order"; then back to London and then to Cornwall. The manuscript was first published in 1888. Another early account is Daniel Defoe's *Tour of England* in 1724, a delightful book full of touches of humour. Several modern editions are available, ranging in price from the two volumes in Everyman's Library to Peter Davies' beautifully printed edition of 1927. After Defoe the eighteenth century produced

no good writer about the country till near the end, when three arose* : Arthur Young and Gilbert White, whom I have already mentioned, and William Cobbett, peasant son of Surrey and one of the most striking figures that ever stalked the English countryside, second only to John Wesley in the impression he made upon the people as he passed. Stern and rugged, hating bitterly everything effeminate and soft, contemptuous of all Jews, stock jobbers, and citizens of London generally, he was an ardent lover of good farmers and good animals. For him land and animals unfit for agriculture were altogether baneful. London was always the "Wen"; the Surrey heaths were abominations; Hindhead "certainly the most villanous spot that God ever made." For him, bread, beer, and bacon were the divinely-ordained foods of an Englishman; tea and potatoes were disgusting if not dangerous: "It is notorious that *tea* . . . besides being *good for nothing*, has *badness* in it." As for the potato: "It will bring English labourers down to the state of the Irish . . . it is the root of slovenliness, filth, misery, and slavery; its cultivation has increased in England with the increase of the paupers: both, I thank God, are upon the decline . . . Englishmen seem to be upon the return to beer and bread." You should have in your library his *Rural Rides*† and also his *Cottage Economy* for its vivid English and its vigorous tirades against the changes then beginning in the countryside. But he had a good eye for the country and his descriptions hold us so that we have to read on.

Next in point of time to tell about the countryside comes George Borrow—another Eastern Counties man. *Lavengro* and *Romany Rye* should be on the farmer's list, though I am not quite sure whether the young people will like them. He doesn't deal with agriculture: he is vexatiously silent about the changes in farming that were then taking place; he was a tramp, or, rather, a super-tramp, who loved the road and the ale-house on the heath, boxing, and horses; he gave us, too, that wonderful creature Isopel Berners, who is surely fit to stand beside Hudson's Rima and Galsworthy's Megan David. But he afterwards married and settled down, and his later books need not go on our list. Wren Hoskyns' *Talpa, or the Chronicles of a Clay Farm* (1847) should be added, if possible the edition with Cruikshank's illustrations. Among the modern writers there is almost overwhelming difficulty of choice. Happily there is growing up to-day a new kind of literature faithfully describing the life of the countryman as it is, yet written with such insight and with so human and personal a touch as to have all the charm of a romance. Truth is, indeed, the secret of all eloquence and virtue. The forerunner was Richard Jeffries, the gamekeeper-writer who charmed our fathers fifty years ago, and his *Wild Life in a Southern County* and *Round About a Great Estate* still deserve a place on our list. Then came W. H. Hudson. His *Shepherd's Life* must be on the list, and, if you are in the West Country, his *Land's End*.

Later ones I put in alphabetical order. There is Adrian Bell—

* This was also the time when François de la Rochefoucauld visited Suffolk (1874). His vigorous account of what he thought of the place and the people should certainly be read by the natives of that county. The Cambridge University Press has published the book (*A Frenchman in England*, 1933).

† William Reeves has a good edition, edited by Pitt Cobbett.

you all know his *Corduroy*, the account of his farming experiences written so vividly that farmers can follow them with delight. George Bourne's biographies of himself (*The Wheelwright's Shop*) and his man Bettesworth (*The Bettesworth Book* and *Memoirs of a Surrey Labourer*) and his *Change in the Village* appeal to a wide circle of readers. Then there is Sassoon, whose *Memoirs of a Fox-hunting Man*, while not an agricultural book, is full of the life of the country; and, of course, A. G. Street, our most recent discovery—a Wiltshire dairy-farmer blessed with a keen eye for human character, a retentive memory, a cheerful outlook on life, and a great gift of writing, so that he can set down the things he has seen and heard and can make his sturdy farm workers talk before us. His *Farmer's Glory* is likely to last a long time.

I shall not, and could not if I wished, attempt to deal with the long list of writers of fiction who localise their stories and so bring in descriptions of people and of scenery recognisable as types by those who know the country. Of course, place must be found for some of these, but the choice must be left to the local expert. Trollope should be included in any list, and in hunting regions perhaps Surtees, though without the illustrations the present-day reader would probably not get far with him. Towering above them all, of course, is Hardy, and no library could leave him out. Nor could Quiller-Couch be omitted from Cornwall or Sheila Kaye Smith's novels from Sussex, or Mary Webb's from Shropshire. Finally, even on the shortest list we should put Victoria Sackville-West's poem *The Land*. It is a beautiful piece of work that would be widely appreciated by country readers.

Of course, there are many more, for happily there have always been men and women who have known something of the joy of the life-giving earth and the peace of a quiet garden, who in their dreams have walked—

Where a voice of living waters never ceaseth
In God's quiet garden by the sea,
And Earth, the ancient life-giver, increaseth
Joy among the meadows, like a tree.

The County Libraries to-day have a great opportunity of introducing good literature to the countryman. It is a time of great changes, social, economic, and technical; old customs are dying out, new ones are not yet established: just the time, indeed, when new tastes can be fostered and the countryman made to realise something of the rich heritage of English literature that has come down to him, and of the worth of some of the books written in our own day.

[*Reprinted from the Journal of Ecology,*
Vol. XXI. No. 1. February, 1933.]

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PRINTED IN GREAT BRITAIN

COLONISATION BY *EPILOBIUM ANGUSTIFOLIUM*

By WINIFRED E. BRENCHLEY AND SIGNE G. HEINTZE.

(*Rothamsted Experimental Station.*)

AN interesting case of colonisation by *Epilobium angustifolium* has recently occurred at Rothamsted. An area of grassland which has been under experiment since 1856 is divided into a number of plots which are annually treated with various combinations of fertilisers, one half of most plots now receiving regular dressings of lime in addition. This treatment has brought about radical changes in the yield and composition of the herbage, which is mown twice a year and never grazed.

The plots continually receiving nitrogen as sulphate of ammonia, with or without mineral fertilisers, have become very acid, a fact which is reflected in the predominance of *Holcus lanatus*, *Anthoxanthum odoratum* or *Festuca duriuscula* according to treatment, the general tendency being for these grasses to occur in tufts instead of as a uniform herbage.

The winter of 1928-9 was characterised by severe frost, followed during the spring and summer by exceptional drought. Under these abnormal conditions the herbage of the unlimed parts of all plots receiving sulphate of ammonia was practically devastated, and the surface of the ground was covered with a mat of decaying vegetation. Recovery was very slow, and it was not until the autumn of 1931 that the herbage on these plots again reached its normal density. In the process of recovery certain changes in composition occurred as a result of the unusual opportunity for colonisation afforded by the less acute competition, the most prominent invader being *Epilobium angustifolium*. In the presence of continued sulphate of ammonia and superphosphate the normal herbage consists chiefly of clumps of *Festuca duriuscula* and *Anthoxanthum odoratum*, with considerable areas of bare ground between, which are covered with a form of dry peat consisting of incompletely decayed dead leaves. Where complete minerals (superphosphate, potash, etc.) are used in conjunction with heavy dressings of sulphate of ammonia the dominant species is *Holcus lanatus*, which also grows in tufts and covers the surrounding bare spaces with a peaty layer of dead leaves. In this case, however, numerous *Holcus* seedlings may spring up on the peat, and in some seasons these are able to establish themselves and cover the area more effectively.

During the process of recovery since 1929, the herbage has resumed its normal *facies* in the main but, when superphosphate only is associated with the sulphate of ammonia, large quantities of *Epilobium angustifolium* have established themselves in the bare spaces between the clumps of grass. When complete minerals are present much less *Epilobium* has obtained a footing. In the latter case the actual opportunity for colonisation was in reality greater, owing to the proximity of large quantities of the invading species just beyond the boundary line within ten yards of one of the plots, whereas that receiving

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THE ACTION ON THE GROWTH OF CROPS OF SMALL PERCENTAGES OF CERTAIN METALLIC COMPOUNDS WHEN APPLIED WITH ORDINARY ARTIFICIAL FERTILISERS.

BY WINIFRED E. BRENCHELEY, D.Sc.

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(With Eight Text-figures.)

INTRODUCTION.

IN the course of a long series of experiments on plant nutrition, carried out chiefly by means of water and pot culture tests, a considerable amount of information has been obtained as to the action on growth of various elements other than those commonly recognised as nutritive. These elements have come into notice in various ways, frequently in correlation with larger investigations upon quite other lines. In some cases this has led to more specific tests, and copper, manganese, boron, zinc, arsenic, silicon and iodine have been dealt with in previous publications (7, 8, 9). Many of the rarer elements came under review in connection with the investigation on boron (10), and it is hoped that opportunity will offer in the future to extend these observations. Meanwhile, in view of the fact that literature dealing with the effect of many elements on plant growth is relatively scanty, it may be of value to other workers in the same field if the results of further work with copper, and certain experiments with vanadium, lithium, titanium and aluminium are put on record. It must be emphasised, however, that the material here presented makes no pretence to be an intensive study of any one of these elements, the aim being to put forward data which may aid in any further investigation of the subject.

COPPER.

IN view of the known toxicity of copper to plants, and of the widespread use of copper compounds in combating plant disease, the question of the effect on plant growth of the element when it is present in the soil has become one of considerable economic importance. It is recognised that while copper compounds alone in solution are very poisonous if supplied to the roots, the harmful action is greatly mitigated if nutrient

salts are also present (6). This reduction of toxicity is still more marked if soil is the substratum, probably owing to the adsorption of much of the copper compound, whereby it is removed from the soil solution and so is rendered innocuous to plant roots. It is still a debatable question as to whether concentrations of copper salts which are too small to be toxic exert a stimulating action on growth. Results are conflicting, and it is probable that the interaction of the many environmental factors involved, together with the species and even the varieties of the plants grown, admit of stimulation in certain cases and negative action in others.

The suggestion that small quantities of copper salts, if mixed with the usual artificial fertilisers, might improve the growth and yield of crops, led to a series of pot culture experiments being instituted at Rothamsted.

Voelcker (51), working with wheat on the light soil at Woburn, had already found a slight stimulation from the use of copper, applied as sulphate or carbonate, ranging from 0.01 to 0.02 per cent. of the quantity of soil used, larger amounts being definitely toxic. In these experiments the soil was unmanured, and when they were repeated with a somewhat richer soil (also unmanured) from another field the degrees of toxicity and of stimulation were less marked, showing that soil influence is a factor which cannot be disregarded.

The quantities of copper salts used in these Woburn experiments were very heavy, 0.01 per cent. copper representing 3.93 gm. copper sulphate ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$) per pot containing 10 kg. of soil, which represents a dressing heavier than those of some of the regular artificial fertilisers applied, and as the aim of the Rothamsted tests was to determine if *small* additions of copper salts would inexpensively improve the action of the usual fertilisers no attempt was made to utilise such heavy amounts.

Experiments were carried out on two soils, one being a light and very acid soil from Cheshire, deficient in phosphate and calcium, but well supplied with sulphate, the other a heavy Rothamsted loam, containing a sufficiency of calcium. Chalk was added to the Cheshire soil to compensate for the acidity and so avoid masking any possible action of the copper sulphate. Four manurial schemes were adopted, with a basis of superphosphate and with constant amounts of nitrogen and potassium in the form of different fertilisers.

Manurial schemes.

1.	5 gm. superphosphate	+ 2.5	gm. ammonium sulphate	+ 2.0	gm. potassium sulphate
2.	5 "	"	+ 2.5 "	"	+ 6.06 .. sylvite
3.	5 "	"	+ 3.28 "	sodium nitrate	+ 2.0 .. potassium sulphate
4.	5 "	"	+ 3.28 "	"	+ 6.06 .. sylvite

706 *Action of Certain Metallic Compounds on Crops*

Each of the above mixtures was combined with 0.5, 1, 2 and 4 per cent. of copper sulphate based on the total weight of fertiliser supplied in scheme 1, and in every case a unit of four similarly treated pots was used. These represented 0, 0.0475, 0.095, 0.19, 0.38 gm. copper sulphate per pot containing 10 kg. of soil. The percentages of copper sulphate were based on the suggestion originally made by the Copper Sulphate Association that 1 per cent. or 2 per cent. might prove beneficial if mixed with superphosphate or other fertilisers.

Goldthorpe barley was sown March 22, 1927, and harvested on August 15. During growth no marked differences due to the copper sulphate dressings were noted, though on a few occasions it appeared as if the heaviest dose had a slightly detrimental effect which, however, was temporary and not persistent. The figures relating to the harvested crops show that the application of copper sulphate in the amounts here tried were of little value on either the light or heavy loams tested. Some slight evidence of increase in the yield of grain was obtained on the Cheshire soil only, with the heavier dressings of copper sulphate, when sodium nitrate was the nitrogenous manure applied, but this was not the case with ammonium sulphate. In Table I the figures for both soils are given for the manurial treatment of superphosphate, sylvinite and sodium nitrate, as representing the case in which some evidence of effectiveness of copper sulphate was obtained on the Cheshire soil. With the other combinations of fertilisers the figures are still more level, and their publication is unnecessary.

Table 1. *Barley treated with copper sulphate; superphosphate, sylvinite and sodium nitrate as fertilisers. Average of four pots.*

CuSO ₄ + 5H ₂ O per pot (gm.)	Dry weight (gm.)			% N		Actual N (gm.)			% dry in green	
	Straw	Grain	Total	Straw	Grain	Straw	Grain	Total	Straw	Ears
Rothamsted soil:										
Nil	32.10	21.49	53.59	0.385	1.74	0.1236	0.3739	0.4975	34.2	82.4
0.0475	32.44	21.80	54.24	0.374	1.81	0.1213	0.3946	0.5159	33.6	82.1
0.095	32.68	20.59	53.27	0.408	1.74	0.1333	0.3583	0.4916	34.4	80.1
0.19	33.06	21.58	54.64	0.386	1.66	0.1276	0.3582	0.4858	33.9	80.8
0.38	33.38	21.90	55.28	0.389	1.69	0.1298	0.3701	0.4999	35.3	72.2
Cheshire soil:										
Nil	29.87	21.01	50.88	0.571	2.21	0.1705	0.4643	0.6348	35.0	82.0
0.0475	29.32	22.70	52.02	0.595	2.14	0.1745	0.4858	0.6603	37.3	81.2
0.095	30.29	21.58	51.87	0.559	2.19	0.1693	0.4725	0.6418	34.4	81.9
0.19	29.89	22.72	52.61	0.548	2.15	0.1638	0.4884	0.6522	35.4	80.3
0.38	31.84	24.66	56.50	0.557	2.00	0.1774	0.4932	0.6706	35.4	79.0

The percentages of nitrogen in the straw and grain show no variation that can be correlated with the copper sulphate dressings, and the actual

amounts of nitrogen present in the harvested crop vary comparatively little within each manurial treatment. The maturity of the straw, as indicated by the percentage of dry matter present at harvest, also showed no influence of the copper sulphate treatment, though it was affected by the type of manuring.

The differences in yield, maturity and percentage of nitrogen induced by the various forms of artificial fertilisers were considerable, emphasising the desirability of continuing to carry out any further work with copper compounds with different combinations of manures as well as on different soils, as it is quite conceivable that interaction between copper sulphate and manure might come into play and have some influence, beneficial or otherwise, on plant growth.

Similar tests were made in the same soils with another variety of barley (Archer Goldthorpe \times Goldthorpe Spratt) in which *Bordeaux mixture* containing 32.5 per cent. copper was used instead of copper sulphate, the heaviest dressings being raised to supply copper equivalent to double the amount used in the first experiment. The actual manurial treatment for each soil was as follows:

5 gm. superphosphate, 2.5 gm. potassium sulphate, combined with

	Bordeaux mixture			
	gm.	gm.	gm.	gm.
2.5 gm. sulphate of ammonia	0	0.148	0.295	0.59
3.218 gm. sodium nitrate	0	0.148	0.295	0.59

Each treatment was replicated four times and the whole series was systematically randomised in arrangement to avoid errors arising from differences in position in the culture house. Observations during growth and comparison of the yields showed that the addition of Bordeaux mixture to complete fertilisers had no beneficial effect on the growth of barley in the two soils tested, the previous suggestion that heavier dressings might be beneficial not being borne out, at least when the copper was supplied in this form.

For comparison with the copper sulphate results the figures with sodium nitrate manuring are given in Table II. Nitrogen determinations were not made in this case, but average heights and number of ears are included to show how little they were affected by the copper treatment.

It was considered unwise to attempt to increase the quantity of copper compounds further, as the heaviest dressing here used corresponds approximately to 1 cwt. per acre, which is probably approaching the danger limit in view of the known toxicity of copper compounds.

Parallel experiments to those with barley were conducted in autumn

708 *Action of Certain Metallic Compounds on Crops*

Table II. *Barley treated with Bordeaux mixture; superphosphate, potassium sulphate and sodium nitrate as fertilisers. Average of four pots.*

Bordeaux mixture per pot (gm.)	Av. height per pot (cm.)	Av. no. ears per plant	Dry weight (gm.)			% dry in green		
			Straw	Ears	Total	Straw	Ears	Total
Rothamsted soil:								
Nil	100.0	9.2	31.16	33.76	64.92	39.47	76.22	52.68
0.148	101.0	9.5	34.20	34.11	68.31	43.11	75.05	54.74
0.295	100.5	9.8	34.01	35.45	69.46	39.87	74.57	52.29
0.590	101.5	9.6	32.80	35.48	68.28	38.52	74.21	51.35
Cheshire soil:								
Nil	92.0	9.4	28.88	30.71	59.59	67.43	88.81	76.99
0.148	93.5	8.8	28.58	22.73	61.31	72.98	89.87	81.12
0.295	92.0	8.8	27.50	31.93	59.43	66.49	89.46	77.13
0.590	94.5	9.3	28.11	32.62	60.73	64.58	89.20	75.82

with *mustard*, as representing a crop that is cut in the green stage instead of when it has reached maturity and ripened seed. The results were identical, as in no case was any beneficial result obtained with copper sulphate or Bordeaux mixture with any of the manurial combinations supplied. Nothing would be gained from a detailed account of these mustard crops, but for comparison the figures of the results are given in Tables III and IV to correspond with those set out for barley in Tables I and II.

Table III. *Mustard treated with copper sulphate; superphosphate, sylvinite and sodium nitrate as fertilisers. Average of four pots.*

$\text{CuSO}_4 + 5\text{H}_2\text{O}$ per pot (gm.)	Av. height per pot (cm.)	Green weight (gm.)	Dry weight (gm.)	% dry in green
Rothamsted soil:				
Nil	67.42	135.45	13.69	10.11
0.0475	67.96	136.96	13.17	9.62
0.095	68.46	139.26	13.01	9.34
0.19	67.34	135.22	13.83	10.23
0.38	63.88	132.02	11.95	9.06
Cheshire soil:				
Nil	49.50	95.57	7.20	7.53
0.0475	58.04	129.91	8.51	6.55
0.095	57.33	124.47	9.01	7.24
0.19	55.83	124.05	9.62	7.76
0.38	45.50	99.17	7.41	7.47

While these experiments were in progress Allison, Bryan and Hunter⁽¹⁾ published their startling results on the improvement in growth effected when very small dressings of copper sulphate were applied to *raw saw-grass* peat in the Everglades of Florida. While this land is naturally so inimical to the growth of most crop plants that they usually fail com-

pletely soon after planting, the application of as little as 30 lb. per acre of copper sulphate was found to encourage good growth and the production of useful crops. The results, as indicated by photographs, are most striking, and are much more clearly marked with copper than with any other of the elements, manganese, boron, chromium, arsenic, zinc, etc., that were tested simultaneously. Fifty-nine species of plants, well distributed over nine well-defined groups, were tested, and with all of them marked stimulation was obtained with copper sulphate. In many cases heavy fruiting plants were produced when check plants grown without copper sulphate failed entirely. Tomatoes showed a particularly good response, and with peas the pods filled out much better. Also, second crops of corn and sorghum grown on the same soil without further addition showed a marked residual effect of the copper sulphate. Attention is drawn to the fact that no manure other than the copper salt was applied to the peat, which is not acid, but has a high lime content, unlike most peaty deposits.

Table IV. *Mustard treated with Bordeaux mixture; superphosphate, potassium sulphate and sodium nitrate as fertilisers. Average of four pots.*

Bordeaux mixture per pot (gm.)	Av. height per pot (cm.)	Green weight (gm.)	Dry weight (gm.)	% dry in green
Rothamsted soil:				
Nil	80.46	133.95	20.49	15.30
0.148	84.65	151.18	23.43	15.50
0.295	86.08	150.65	21.72	14.42
0.590	81.38	137.70	20.44	14.84
Cheshire soil:				
Nil	77.91	160.60	23.20	14.45
0.148	79.85	148.30	19.71	13.29
0.295	85.23	148.33	22.75	15.34
0.590	70.46	137.23	19.43	14.16

In view of these American results, tests were carried out on English peats. Nothing resembling the saw-grass peat is obtainable in this country, but the work was done with a fenland peat from Suffolk, with a pH value of 7.75, contrasted with a typical acid peat from Dartmoor of pH 4.57. Pot culture experiments were made with barley, rye and turnips, copper sulphate at the rate of 0.8 gm. per pot being added to one half of two series grown with and without artificial fertilisers, the remainder receiving no copper dressing. Owing to the difference in the constitution and the water content of the two peats as delivered, each pot contained 5 lb. of acid Dartmoor peat or 16 lb. Suffolk peat when filled to the same level. The two peats were utterly different in nature,

710 *Action of Certain Metallic Compounds on Crops*

that from Dartmoor being a true fibrous peat, which was broken up and finely sieved, whereas that from Suffolk was more like a dense black loam, of a very light nature. The manurial scheme throughout was as follows:

Fertilisers per pot, where applied { Superphosphate 5 gm.
Ammonium sulphate 2.5 gm.
Potassium sulphate 2 gm.

Combination of manures and copper sulphate

A	No	$\text{CuSO}_4 + 5\text{H}_2\text{O}$	No manure
B	With	$\text{CuSO}_4 + 5\text{H}_2\text{O}$	No manure
C	No	$\text{CuSO}_4 + 5\text{H}_2\text{O}$	With manure
D	With	$\text{CuSO}_4 + 5\text{H}_2\text{O}$	With manure

Barley.

Archer Goldthorpe \times Goldthorpe Spratt seed was sown on February 29 and germinated satisfactorily in both soils. Throughout development the plants in the *acid* peat were the more healthy, and they ripened a fortnight earlier than on the alkaline soil (July 30 on acid, August 13 on alkaline peat). Nothing comparable to the Florida results was obtained as regards the failure of this or any other crop to grow in the peat unless small amounts of copper sulphate were added. Growth was very irregular on both soils and the variations between duplicate pots were so large that no reliance can be placed upon the mean figures, which are therefore not published in case false conclusions should be drawn therefrom. These variations were unavoidable, as owing to the peculiar water-holding capacity of the peat, coupled with the ease with which water is lost by evaporation, especially from the acid peat, the soil tends to "pack" differently from pot to pot, rendering the experimental conditions much more irregular than when ordinary loam soil is used for similar experiments. It was, however, evident that though the use of a mixed fertiliser increased the yield and the amount of nitrogen passed into the crop, the action of copper sulphate was probably negative, as the variations in green and dry weight, nitrogen content, etc., in the presence and absence of copper sulphate were very irregular and varied in either direction. The height of the unmanured plants was appreciably increased by the use of copper sulphate, but this effect was masked in the presence of fertilisers.

On the alkaline peat the leaves became yellowish at an early age and eventually were streaked and spotted with brown, the whole plant becoming increasingly unhealthy in appearance. The whole set inclined to a "spread-eagled" habit, instead of growing upright as is normal. The earing shoots were later in appearing than on the acid Dartmoor peat, and the ears seemed to be smaller and more behindhand in development.

Maturation was delayed and the plants were not ready for harvesting until a fortnight after those on the acid peat.

Copper sulphate had no evident effect upon dry weight yields nor upon total nitrogen content. The yields were not increased by the addition of complete fertilisers on this soil, though the nitrogen content was considerably raised.

Rye.

Garton's seed sown on February 29 was ready for harvesting from both soils on September 18. Throughout growth the difference in appearance with the various treatments was not very obvious. The plants receiving manure tended to be rather stronger than those without, and the plants on alkaline soil to be taller than those on acid peat (Figs. 1, 2). On the acid peat the addition of copper sulphate caused appreciable increase in height in the unmanured plants and a certain increase, which might possibly be significant, in those receiving fertilisers. This result with the unmanured plants tallies with that obtained with barley. On the alkaline soil a slight increase in height occurred with copper sulphate on unmanured plants, though it is doubtful if it was sufficiently large to be significant, but no rise occurred in the presence of fertilisers. The same criticism of the variety of the mean results applies as with barley, but here again it seemed evident that copper sulphate had no significant action in improvement of growth.

Turnips.

Carter's "Snowball" was sown on August 23, and harvested on December 10, the behaviour of the crop in the two peats being radically different from the outset.

On the acid peat germination was considerably delayed and the seedlings were yellowish, growing very slowly and poorly at first. A considerable improvement set in during October, but the plants were still very small at harvest time. One noticeable feature was the entire absence of fungus disease on the leaves, whereas those in the alkaline peat were covered with white patches due to attack.

In the absence of fertilisers an increased yield was obtained with copper sulphate, but this may have been influenced by the very bad start made by the plants. Fertilisers induced some yield increase which is more likely to be a true effect, judging by the appearance and growth of the plants. The percentage of nitrogen in the whole plant was very little influenced either by the fertilisers or the copper sulphate, and



Fig. 1. Rye grown on acid peat. Left to right: no manure, no copper sulphate; no manure, with copper sulphate; with manure, no copper sulphate; with manure, with copper sulphate.



Fig. 2. Rye grown on alkaline peat. Left to right: no manure, no copper sulphate; no manure, with copper sulphate; with manure, no copper sulphate; with manure, with copper sulphate.

consequently the total nitrogen taken up followed the irregular yields with the different treatments.

On the alkaline peat germination was rapid and the seedlings grew well, soon making large plants with dark green leaves, in striking contrast to those in the acid peat. In this case, the only one in all the experiments that may exceed experimental error, a heavier yield was obtained by the addition of copper sulphate to complete fertilisers. The increase was obtained in both leaves and "bulbs" of the duplicate pots, and it is just possible that this is a true result, and the figures are therefore given for reference (Table V). No similar increase was obtained when no manure was added. In this case the percentage of nitrogen when fertilisers and copper sulphate were combined was rather lower than with the other treatments, which all gave parallel results. Even so, the total nitrogen absorbed was considerably greater owing to the marked increase in yield.

Table V. *Turnips, grown with and without copper sulphate and complete fertilisers. Means of duplicate pots.*

	Green weight (gm.)		Dry weight (gm.)			% N in total dry matter	Actual N in total dry matter (gm.)
	Leaves	"Bulbs"	Leaves	"Bulbs"	Total		
Acid peat:							
No Cu + no manure	24.81	3.67	2.58	0.41	2.99	5.08	0.152
Cu + no manure	37.93	4.30	4.24	0.45	4.69	5.16	0.242
No Cu + manure	43.82	9.26	5.44	0.94	6.38	5.24	0.334
Cu + manure	40.01	4.20	4.97	0.47	5.44	5.18	0.282
Alkaline peat:							
No Cu + no manure	104.63	58.03	15.55	4.20	19.75	4.54	0.896
Cu + no manure	138.84	40.18	17.96	3.23	21.19	4.56	0.966
No Cu + manure	100.87	37.75	18.34	3.15	21.48	4.51	0.969
Cu + manure	168.15	96.27	24.67	8.19	32.86	3.73	1.226

Summing up these results it was quite obvious that, in spite of the general irregularity in growth with all crops, no parallel result was obtained to that of Allison, Bryan and Hunter⁽¹⁾ by the addition of copper sulphate to unmanured peat, whether alkaline or acid in reaction. In no case did the copper sulphate cause any improvement which might exceed experimental error.

With barley and fye copper sulphate was also of no benefit when added with a complete fertiliser. With turnips, however, a certain definite increase of crop was obtained which may possibly have been influenced by the copper sulphate, though this assumption needs confirmation.

VANADIUM.

In connection with the use of various types of slag as fertilisers, investigations were made in 1924 and 1925 on the effect of the degree of the fineness of grinding of the slags on their value as phosphatic manures. Theoretically, finer grinding should tend to increase the manurial value of slag by aiding the availability of the contained phosphates. Actually, it was found in pot experiments that this was not always so, but that in some cases the more finely ground slags were less effective than the coarser grindings.

The experiments were carried out in Rothamsted soil, mixed with 10 per cent. sand to lighten it, with an adequate basal dressing of nitrogen and potash (as ammonium and potassium sulphate) throughout. The slags, ground to three degrees of fineness, were used in quantities supplying phosphate equivalent to that in the superphosphate given to the control pots, a second set of controls receiving no phosphate at all. Barley and mustard were each grown for two seasons, the total crop results being set out in Table VI.

Table VI. *Barley and mustard grown with slag ground to three degrees of fineness. Basal dressing of sulphates of ammonia and potash. Dry weight (total). Mean of four pots.*

	Barley (gm.)		Mustard (gm.)	
	1924	1925	1924	1925
	Gold-thorpe	Spratt Archer		
Slag passing sieve of mesh 100	52.72	35.81	18.51	15.47
" 120	52.60	39.22	17.00	15.07
" 180	52.73	38.31	17.33	13.70
No phosphate	59.79	30.77	10.73	9.49
Superphosphate	60.48	43.82	19.01	18.58

In 1924 the addition of phosphate was superfluous to the Goldthorpe barley, equal crops being obtained from the two sets of controls. In the presence of slag, however, the yield was considerably reduced, and as this could not be attributed to any failure in the phosphate supply, suspicions were aroused as to the possibility of some toxic agent being present in the slag. This was corroborated to some degree the following year, and strengthened by the behaviour of the mustard in which the yield decreased with the increased fineness of the slag. Similar indications, though less marked, were obtained with another slag, and as analysis showed the presence of a certain quantity of vanadium in the slag, steps were taken to determine the action of this element on growth.

Seedlings of Spratt Archer barley were set up in water culture early in March, in the usual Rothamsted nutrient solution to which vanadium chloride (VOCl_2) had been added to give a range of concentrations from 1 : 5000 to 1 : 15,625,000. The concentrations were planned to decrease geometrically by $\frac{1}{5}$, but a few interpolations were made at possible critical points.

With 1 : 5000 VOCl_2 the seedlings were seriously checked from the first, very little growth was made, and within six weeks they were quite

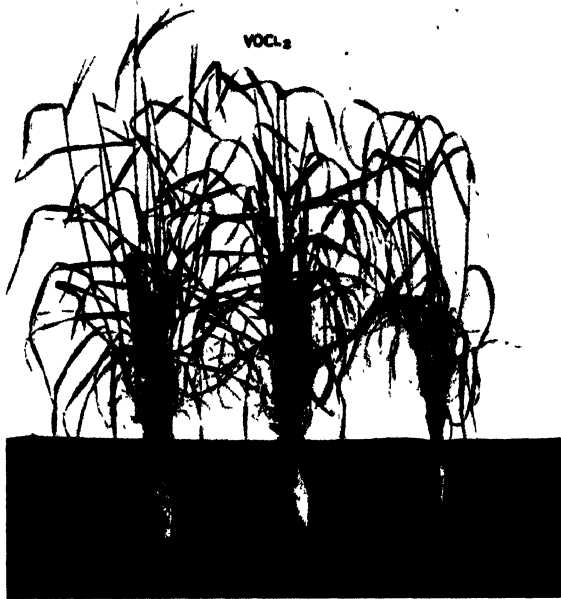


Fig. 3. Barley grown in nutrient solution with vanadium chloride.

Left	Control; no vanadium chloride
Middle	1 : 3,125,000 vanadium chloride
Right	1 : 25,000

dead. With 1 : 25,000 VOCl_2 signs of injury soon became evident, as root growth was checked and less roots were produced, though the shoots developed normally at first. Later on weakness became manifest in the shoots, less tillers were formed, and though the plants developed in a normal way a slight depression persisted throughout and was indicated by a lowered dry weight at harvest (Fig. 3). A similar depression in the shoot, becoming less marked with decreasing concentration, was shown down to and including 1 : 2,000,000 VOCl_2 , but the dry weight of the next two sets was probably affected by an unhealthy black affection of the root

716 *Action of Certain Metallic Compounds on Crops*

which obscured the true vanadium effect. In the roots no sign of adverse effect was observed in lower concentrations than 1 : 25,000 VOCl_2 . The lowest strength of all, 1 : 15,625,000 VOCl_2 , gave plants parallel to the controls, without any indication of stimulation (Fig. 4).

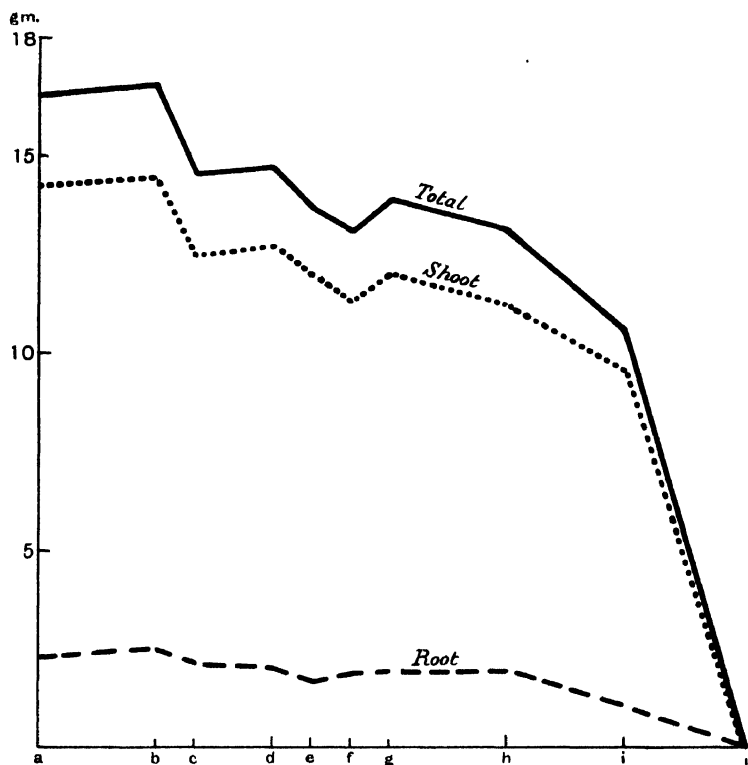


Fig. 4. Dry weights of barley grown in nutrient solution with vanadium chloride, March 9–June 12.

a, Control	f, 1 : 1,000,000 vanadium chloride
b, 1 : 15,625,000 vanadium chloride	g, 1 : 625,000 "
c, 1 : 10,000,000 "	h, 1 : 125,000 "
d, 1 : 3,125,000 "	i, 1 : 25,000 "
e, 1 : 2,000,000 "	j, 1 : 5,000 "

The depressing effect on plant growth of minute traces of vanadium was thus clearly demonstrated, and the water culture results lend considerable support to the assumption that the presence of this element was responsible for the failure of finely ground slags to give as good manurial results as superphosphate containing the same amount of phosphate. Among earlier workers Ramírez (31) found that vanadium can be absorbed and stored by plants, with resulting anomalies in growth, while Ducloux and Cobanera (14) working with *Pisum sativum* indicated that the effect

of vanadium on root growth is depressing, often to a considerable extent, whereas any possible stimulation is slight and is confined to the leaves, which may show traces of the element as a storage product. This proved toxicity of vanadium may be of more economic importance than has hitherto been recognised, as the element is a recognised constituent of certain soils. Robinson⁽³⁶⁾ reported from 0.01 to 0.08 per cent. in all of a number of important American soil types, similar evidence being furnished by Thomas⁽⁴⁶⁾ for Pennsylvanian soils, and doubtless further analyses would reveal its presence in many soils in other parts of the world.

LITHIUM.

The presence of lithium in plants has been recognised for many years. Gaunersdorfer⁽¹⁷⁾ showed that for some plants this element is a constant though not necessary constituent, and some years later Tschermak⁽⁴⁷⁾ made a wide search for the element, finding it in forty-five species, distributed throughout seventeen natural orders, notably Compositae, Solanaceae and Ranunculaceae. His list of plants examined, but found to be *free* from lithium, ran into hundreds, indicating that the element is by no means of universal distribution in the plant kingdom. Robinson, Steinkoenig and Miller⁽³⁷⁾ found lithium present in spectroscopic quantities in all plants in forty-eight species embracing a range of legumes, vegetables, grasses, trees and bushes.

Gaunersdorfer's work on *Cicer arietinum*, *Vicia faba*, *Glycine hispida*, *Tropaeolum*, *Salix fragilis*, etc., indicated that for most plants lithium is poisonous in relatively small quantities, but that a measure of protection is afforded by the fact that the fully grown leaves are affected, and that the lithium compounds if presented in low concentrations do not enter the younger leaves or the meristematic tissues. The poisoned older leaves shrivel and die, thereby removing part of the harmful metal from the plant and from the soil.

The accumulation of lithium in the older leaves was corroborated by Petri⁽³⁰⁾ who worked on olive trees and found that the chlorophyll of affected leaves was partly destroyed, and the lamina dried out if sulphate of lithium or certain other toxic compounds was added to the usual water supply. Gaunersdorfer stated that lithium travels upwards with the transpiration current and also in a lateral direction by way of the woody cell walls. Rankin⁽³²⁾ provided further evidence of this by feeding chestnut trees with solutions of lithium nitrate, when it was found that the compound penetrated to all parts of the trees where active translocation

718 *Action of Certain Metallic Compounds on Crops*

of food materials occurred, i.e. to all parts of the bark and sapwood both above and below the point of insertion of the lithium nitrate, while in small trees complete penetration of the heart-wood was obtained. Attempts were made by Rumbold⁽³⁸⁾ to utilise this fact for the control of the devastating chestnut blight (*Endothia parasitica*) by injecting toxic salts into the trees. Lithium carbonate and lithium hydroxide were at first efficacious, as a callus formed between the diseased and the sound tissues, the former eventually drying out. The lithium, however, was gradually eliminated from the trees, which thereupon became subject to reinfection.

Ravenna and Zamorani⁽³⁴⁾, and later Ravenna and Maugini⁽³³⁾, investigated the possibility of replacing potassium by lithium as a nutrient element, and demonstrated the harmful effect of lithium on various plants which differed in the degree of injury exhibited, soy beans being the most, and maize the least susceptible among the plants tested. Experiments with tobacco, supplied with varying amounts and proportions of potassium and lithium salts, gave some indication that this plant may be able to utilise certain small proportions of lithium salts. On the other hand, Hahn⁽¹⁸⁾ reported that lithium compounds in the presence of potassium compounds do not influence the growth of wheat in water cultures during the first period of vegetation, whereas in the later period the growth of the plants is rather retarded and the formation of grain prevented.

The most detailed work as to the action of lithium on wheat and barley was carried out by Voelcker⁽⁵⁰⁾ at Woburn from 1900 to 1912 in connection with the Hills Pot Culture Experiments. Several compounds were tested, the general results being that all concentrations above 0.0018 per cent. of lithium in the soil were increasingly toxic, retarding germination and reducing yield. Smaller quantities of lithium given in the form of phosphate, carbonate and especially nitrate appeared to have some stimulating action, improving growth and increasing yield, 0.001 per cent. lithium being the effective amount. At the same time that Voelcker was demonstrating the possible stimulating effect of lithium compounds when added to soil, water culture experiments were being carried on at Rothamsted to determine the action of lithium chloride when the factor of absorption of the toxic compound, such as occurs in soil, was eliminated. Barley was grown in a complete nutrient solution¹ (Rothamsted—pH 3.6) with the addition of 1 : 10,000 to 1 : 20,000,000

¹ KNO₃, 1 gm.; MgSO₄, 0.5 gm.; KH₂PO₄, 0.5 gm.; NaCl, 0.5 gm.; CaSO₄, 0.5 gm.; Fe₂Cl₆, 0.04 gm.; distilled water to make up 1 litre.

parts of lithium chloride. No change of solution was made during growth, and the plants were harvested after 43 and 53 days respectively in spring and summer tests (March 8–April 20, May 7–June 29).

In the *spring* test the growth of the shoots did not appear to be much affected by any concentration of lithium chloride, and the dry weights showed no differences that could be regarded as significant. With 1:10,000 lithium chloride the roots were adversely affected, being thickened, short and bunchy, tending to remain at the surface of the nutrient solution instead of entering it freely. Nevertheless, they were among the heaviest in dry weight of the whole series. Improvement in type of root development occurred with decrease in lithium chloride concentration, those in 1:100,000 lithium chloride being quite normal. The difference in the total dry weights in the various concentrations did not follow any regular sequence, and it was not possible to attribute any toxic or stimulant action to the lithium chloride, though the higher figures with some of the greater dilutions may be referred to on account of later results (see Fig. 5). Similar stunting and thickening of the roots of barley had previously been recorded by Voelcker⁽⁴⁹⁾ for plants grown in water culture containing 1:5000 and 1:10,000 parts of oxide or iodide of lithium, the injurious effect being more marked with the latter, which introduced a second harmful factor in the iodine present.

In the *summer* test at Rothamsted the thickening and bunchiness of the roots with the stronger lithium chloride concentrations were not noticeable, but with 1:10,000 the tips of the lower leaves were much discoloured, becoming yellowish brown, suggestive of typical injury by poisoning. The general growth and the dry weight showed no definite response to any concentration except 1:10,000,000 lithium chloride. In this case the plants were much above average strength, with sturdy shoots and well-developed roots. So much growth had been made that the plants were nearing the end of their nutritive resources in the unchanged solutions, as was evidenced by a tendency to redness in the stem colour, which in barley is a typical sign of shortage of some essential nutrient, as nitrogen or phosphorus. The dry weight of both root and shoot was more than double that obtained with any other strength of lithium chloride or in the controls without lithium (Table VII, Fig. 5). The increased dry weight was proportionally greater in the root than in the shoot, and is clearly indicated by the reduction in the shoot root ratio as compared with that in other concentrations.

The tolerance of barley for lithium chloride in the presence of nutritive salts is therefore considerable. This is shown still more clearly

Table VII. *Barley grown with lithium chloride (mean of five plants). May 7–June 29.*

	Dry weight (gm.)			Shoot/root ratio
	Shoot	Root	Total	
Control; no LiCl	0.793	0.106	0.899	7.48
1: 10,000 LiCl	0.857	0.120	0.977	7.14
1: 50,000 "	0.752	0.111	0.863	6.77
1: 100,000 "	0.684	0.111	0.795	6.16
1: 500,000 "	0.751	0.100	0.851	7.51
1: 1,000,000 "	0.632	0.078	0.710	8.10
1: 5,000,000 "	0.829	0.115	0.944	7.21
1: 10,000,000 "	1.861	0.353	2.214	5.27
1: 20,000,000 "	0.771	0.096	0.867	8.03

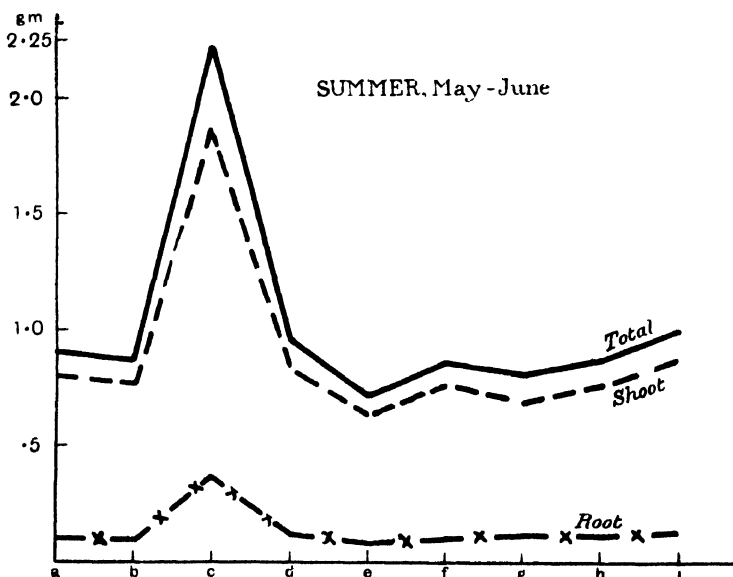
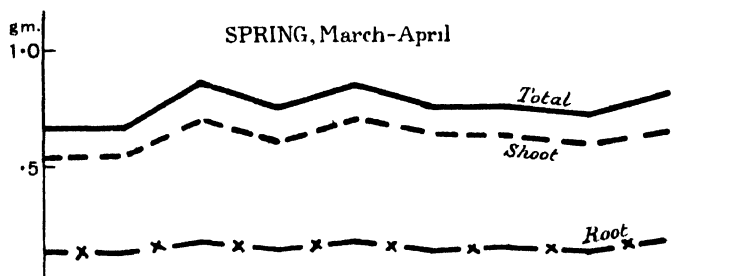


Fig. 5. Dry weights of barley grown in nutrient solution with lithium chloride, March 8–April 20, May 4–June 24.

a, Control
b, 1: 20,000,000 lithium chloride
c, 1: 10,000,000 "
d, 1: 5,000,000 "
e, 1: 1,000,000 "

f, 1: 500,000 lithium chloride
g, 1: 100,000 "
h, 1: 50,000 "
i, 1: 10,000 "

by comparison with plants grown in similar solutions with a stronger poison such as copper sulphate.

Concentration 1 : 10,000	<i>Lithium chloride</i> Growth not affected	<i>Copper sulphate</i> Plants killed outright, no development of seedlings
1 : 5,000,000	Growth not affected	Much depressed. Dry weight less than half that of control plants

Buckwheat, grown in similar solutions from May 4 to June 4, was, however, severely injured by 1 : 10,000 lithium chloride, the shoots being killed or very weakly, all the lower leaves being dead, while the roots were extremely poor and undeveloped (Fig. 6). The appearance of the

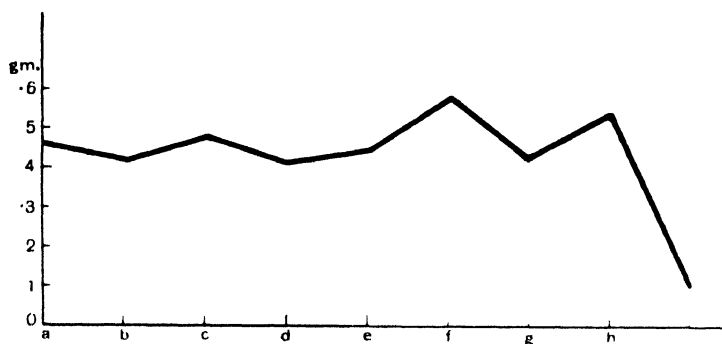


Fig. 6. Total dry weights of buckwheat, grown with lithium chloride, May 4–June 4. Same concentrations as for barley, Fig. 5.

dead leaves suggested a deposit of poisonous salts therein, but with weaker strengths from 1 : 50,000 lithium chloride downwards, no signs of similar injury were manifested. No suggestion of stimulation, as occurred with 1 : 10,000,000 concentration in the summer barley tests was obtained, the dry weights varying considerably among themselves, with no regular sequence.

TITANIUM.

Titanium appears to be one of the most generally distributed of the rarer elements in plants. Robinson, Steinkoenig and Miller⁽³⁷⁾ determined its presence in very small amounts in every species they examined, forty-eight in all, covering a great variety of types. Bertrand and Spirt⁽⁵⁾ carried out more comprehensive analyses, their results leading them to suggest that titanium occurs in all phanerogamic plants, largely in the leaves and green parts. Some seeds are very rich in titanium, which is almost entirely localised in the integuments, parenchyma tissues usually

722 *Action of Certain Metallic Compounds on Crops*

being poorly supplied. In some cases relatively large quantities are present, the most notable instances being:

Maté, leaf and stem	...	...	2332.0 mg. in 1 kg. ash	
Strawberry, fruiting receptacle			967.0	„
<i>Theobroma cacao</i> , seed	...		878.0	„
Maize, grain	...	...	109.0	„
Carrot, leaf	...	...	200.0	„

And for comparison:

Carrot, root	...	...	75.0	„
Wheat, grain	...	...	45.0	„
Oats, grain	...	...	35.5	„
Barley, grain	...	...	33.6	„

Askew (2), after determining the titanium content of New Zealand soils and plants, found that soils reputed to give rise to bush sickness in cattle contained a very low proportion of titanium, and suggested that some association may exist between the presence of this element and the production of pasture suitable for healthy animal development.

In view of certain suggestions that small quantities of titanium compounds, if added to the ordinary combination of artificial fertilisers, might increase their efficiency and result in increased crop yield, pot culture experiments with mustard were carried out in 1930 on two soils. These were the same as were used in the experiments with copper (see p. 705) and the general treatment was similar. Ground titanite (B) and a compound titanium fertiliser (A) of similar composition¹ were tested, both alone and in conjunction with other artificial manures, applied at the rate of

	1.2 gm. per pot of titanium compound,
and	<div style="display: inline-block; vertical-align: middle;"> <div style="display: inline-block; vertical-align: middle; font-size: 3em; line-height: 1;">{</div> <div style="display: inline-block; vertical-align: middle;"> 3.0 „ superphosphate, 2.5 „ potassium sulphate, 2.5 „ sodium nitrate. </div> </div>

As the Cheshire soil is very deficient in lime, some pots were put up without lime to determine whether the lime in the titanium compound was beneficial, though this was known to be unlikely on account of the smallness of the dressing. Mustard was sown on May 22 and harvested July 18.

On the light *Cheshire* soil the plants grown without lime were hope-

¹ Lime, 28.3 per cent.; silica, 30.3 per cent.; titanium oxide, 40.4 per cent.; manganese peroxide, 1.0 per cent.; total, 100.0 per cent.

lessly small and stunted, and the addition of titanium fertiliser had no effect. Liming, without manure, caused a certain improvement, which was much augmented by dressings of artificials, but here again no increased benefit was obtained from the use of titanium fertilisers. This was the case as regards the dry weight percentage and actual quantity of nitrogen taken up, and in the ratio between the dry and green weights of the plants at harvest time.

Where the plants were abnormally small, as when no lime was given, more plants were left per pot to give every possible opportunity for the titanium fertiliser to show its action on growth. For a strict comparison with better grown plants, therefore, the figures in these cases are probably higher than they should be, but as the discrepancy was already so great this is of no account. A consideration of the figures in Table VIII show that in this soil mustard received no benefit from the use of either of the titanium fertilisers.

Table VIII. *Cheshire soil. Average results from three pots.*

	Av. height per pot (cm.)	Green weight (gm.)	Dry weight (gm.)	% dry in green	% N in dry	Actual N (gm.)
No lime:						
Titanium fertiliser, A	13.9	1.80	0.288	16.00	Not determined	
Titanite, B	8.3	1.27	0.186	14.60	"	
No manure	23.2	1.00	0.152	15.20	"	
Full artificials	20.2	4.45	0.701	15.75	"	
A + full artificials	22.7	4.05	0.689	17.00	"	
B + full artificials	19.7	3.28	0.566	17.30	"	
With lime:						
No manure	40.9	28.90	4.270	14.78	3.50	0.150
Full artificials	73.1	87.00	16.910	19.44	2.44	0.413
A + full artificials	67.8	92.60	17.960	19.39	2.44	0.438
B + full artificials	76.9	87.30	16.760	19.20	2.43	0.407

Table IX. *Rothamsted soil. Average of three pots.*

	Av. height per pot (cm.)	Green weight (gm.)	Dry weight (gm.)	% dry in green	% N in dry	Actual N (gm.)
Titanium fertiliser, A	98.5	79.4	15.41	19.41	1.99	0.307
Titanite, B	85.2	74.6	15.02	20.13	2.00	0.300
No manure	95.2	78.7	15.63	19.86	2.10	0.328
Full artificials	77.6	91.7	17.41	18.99	2.73	0.475
A + full artificials	88.3	98.5	17.97	18.24	2.56	0.459
B + full artificials	68.9	86.0	17.32	20.14	2.53	0.438

On the heavier *Rothamsted* soil the plants were strong and well developed, those not receiving a dressing of full artificials being somewhat smaller than the rest. At no stage was any benefit apparent from the use

of either titanium fertiliser, and this was borne out by the figures obtained after harvesting, as shown in Table IX.

The dry weights of plants receiving only titanium fertilisers A or B were practically the same as where no manure of any sort was applied, and this also occurred where complete artificials were added to the titanium fertilisers. The proportion of dry matter in green, the percentage of nitrogen and the total nitrogen present all remained unaffected by the titanium fertilisers, both in the presence and absence of other artificials.

There was thus an entire lack of response to the added titanium on the two soils tested with mustard, and no further opportunity has arisen of testing other soils and crops with a wider range of dressings with titanium compounds.

ALUMINIUM.

Aluminium has of recent years attracted a great deal of attention because of its relation to problems of soil acidity, and much has been written on the subject. It is not proposed to discuss this matter, but attention must be drawn to the work of Hardy (19), Line (24), Magistad (28) and others in this connection.

From the physiological point of view the interest lies in the part aluminium may play in plant nutrition, and in its possible toxic or stimulating action upon growth. It is not surprising that an element so abundant in all soils should prove to be a frequent constituent of plant tissues. Towards the end of last century many workers were active in determining the presence of aluminium in various plant species. Church (12) noted the occurrence of aluminium in certain cryptogams, as much as 33.5 per cent. being found in the ash of *Lycopodium alpinum*. Dunnington (15) determined its presence in various weeds, including *Verbascum thapsus* with 1.15 per cent., and *Rumex obtusifolius* with 0.45 per cent. Al_2O_3 in the ash. Ricciardi (35), after estimating the aluminium content of various plants, concluded that the assimilation of alumina does not depend upon the percentage in the soil, and that generally speaking it is most abundant in the trunk and branches, less plentiful in the seeds and least abundant in the leaves. He expressed his belief that alumina occurs in the most assimilable condition in soils that are not very calcareous, such as clay soils, whereas on chalky soils it is in a less available state. Ricciardi's record as to the distribution of aluminium in plant tissues was corroborated later by Berthelot and André (4), who reported that alumina is present in considerable quantity in plants with extensive root systems (alfalfa roots 0.127–0.5 per cent.,

convolvulus roots 0.0596–0.4 per cent., Bermuda grass 0.011–0.12 per cent.), but that it remains largely in the roots and is found only in minute quantities in the leaves (lupin leaves 0.013–0.037 per cent., linden leaves 0.0012–0.0025 per cent.).

Many of the earlier records of the occurrence of aluminium in plants were summarised by Langworthy and Austen⁽²³⁾, who gave a list of authors and their chief results. The majority of plants contain only small amounts of aluminium, usually below 1 per cent. of ash, with certain noteworthy exceptions. Sayre⁽³⁹⁾ reported 11.13 per cent. of ash in the root of *Taraxacum*, 18.07 per cent. of this being Al_2O_3 . Smith⁽⁴¹⁾ found abnormal quantities in *Orites excelsa* R.Br. (Proteaceae), in which aluminium appears to be an inorganic constituent necessary for growth, any excess being deposited in the cavities and natural fissures of the wood as basic aluminium succinate. Normal specimens of the tree contain 35–45 per cent. Al_2O_3 in the ash, but the tendency is for still more to be absorbed, up to 80 per cent. on occasions when conditions are suitable for the deposition of aluminium succinate.

Methods for the microchemical detection of aluminium in plant tissues were revised by Kratzmann⁽²¹⁾, who examined 130 plants, corroborating the wider distribution of the element in the plant kingdom. Many cryptogams show accumulation of alumina in the sporophylls, while it tends to be concentrated in the blossoms of phanerogams. Stoklasa⁽⁴⁵⁾ also put together much of the available information as to the distribution and function of aluminium in the plant world.

It is outside the scope of the present paper to attempt to summarise the work done on the harmful effect of aluminium compounds on plants growing under ordinary soil conditions, but attention may be drawn to a few references which indicate the type of results obtained (11, 20, 25). It is desired rather to follow up the idea that aluminium may also be a stimulating agent or even an essential nutritive element.

Stoklasa⁽⁴⁴⁾ indicated that generally speaking very small amounts of aluminium salts benefit seed germination, larger amounts being toxic. The action appears to vary with the species, as Varvaro⁽⁴⁸⁾ found that aluminium oxide has a retarding effect upon the germination of beans but acts as an accelerator of this process in maize. This is of interest in that a few years later Mazé⁽²⁹⁾ claimed that small quantities of aluminium were necessary for the optimum development of maize, in common with such elements as boron, fluorine and iodine. The same species, as well as *Vicia faba*, *Lens esculenta* and *Helianthus annuus*, was improved by salts of aluminium of 0.0001 per cent. concentration, though growth was

hindered by 0.005 per cent. (Kratzmann⁽²²⁾). Sommer⁽⁴²⁾ suggests that aluminium may be essential to millet, as in controlled experiments growth was markedly improved in its presence, peas also showing a small increase in total dry weight and a certain improvement in seed production. The question of the toxicity of aluminium is complicated by its correlation with the acidity of the nutrient medium. Increasing concentrations of aluminium salts added to culture solutions tend to bring about slight but progressive increases in the H-ion concentrations of the solutions, due to hydrolysis of the aluminium salts. In any particular case, therefore, it is necessary to be aware of the effect of varying H-ion concentrations before estimating the effect of aluminium on growth. The general consensus of opinion appears to be that aluminium exerts a toxic influence on its own account, quite apart from its effect upon the acidity of the nutrient solutions. Barnette⁽³⁾ claimed that 0.5 mg. or more per litre of aluminium supplied as nitrate, sulphate or chloride, was harmful to the growth of wheat seedlings, causing decrease in dry weight, and that little, if any, of the deleterious action was due to increased H-ion concentration. Similar conclusions were reached by Conner and Sears⁽¹³⁾, with barley, who also found that the poisoning effect was reduced if much phosphate was present. They attributed the toxicity of acid soils for many plants to the presence of easily soluble aluminium salts. A parallel problem was attacked later by McLean and Gilbert^(26, 27) who again demonstrated the harmful action of aluminium when in contact with barley roots, even when presented in a non-diffusible colloidal form. The lower toxic limit was about 16 parts aluminium per million, but soluble phosphate in equivalent concentrations completely counteracted the toxicity, while from 3 to 13 parts of aluminium per million acted as a stimulant to growth.

Pineapples appear to be less susceptible to aluminium poisoning (Sideris⁽⁴⁰⁾), being uninjured by nutrient solutions containing 25 parts per million of the element, larger amounts being tolerated in soil, since when soluble aluminium salts are added to soil the greater part of the aluminium is removed from the solution. Spencer⁽⁴³⁾ studied the relation between aluminium and acidity in sand cultures with *Rhododendron ponticum* L., young seedlings potted in white quartz sand being supplied with constantly renewed nutrient solution, and he found that in general the toxic action of aluminium decreased as the acidity of the solution increased. At pH 5.5 aluminium was toxic even at a concentration of 1 part per million, whereas at pH 3.0 a very noticeable stimulating effect occurred with 3 parts per million.

Little information is available as to the physiological action underlying the toxicity or stimulation of aluminium. With *Aspergillus niger* and *Penicillium glaucum* Zehl⁽⁵²⁾ found that the poisonous effect of many compounds, including aluminium sulphate, increased with rise of temperature, the toxicity rising much more rapidly than the temperature. No definite cause for this action was ascertained, as Zehl did not think it was wholly explained by the increased ionisation of the salts at the higher temperatures. Water plants as *Spirogyra*, *Elodea* and *Lemna* exhibited reduction of starch in the presence of aluminium compounds, assimilation being checked but not entirely inhibited, a certain amount of plasmolysis occurring as well. Fluri⁽¹⁶⁾ believed that the aluminium salts act on the diastases, thus partly accounting for the reduction in starch, and that if grape sugar or glycerin is added to culture containing aluminium compounds, the injurious action of the latter is prevented.

At Rothamsted, aluminium was one of a series of elements examined for their possible stimulating action on plants grown in water cultures, barley, peas and maize being grown.

Barley.

Preliminary tests (March 6–April 21), were made with potash alum ($\text{Al}_2(\text{SO}_4)_3 + \text{K}_2\text{SO}_4 + 24\text{H}_2\text{O}$), which proved definitely toxic in concentrations from 1:1000 to 1:100,000, but showed no indications of benefiting growth in lesser quantities down to 1:100,000,000. This was inconclusive, owing to the second variable of potash in the alum, and later tests were made with aluminium sulphate, providing aluminium to correspond in quantity to that in the potash alum test. This provided a set of cultures with aluminium sulphate ranging from 0.733:1000 to 0.733:100,000,000. The first trial, from March 19 to May 11, gave results corresponding to those with potash alum, though the plants were larger, owing to the more favourable growing season. The strongest concentration, 0.733:1000, was again fatal to development, and was omitted from the main series set up later.

Three sets of Plumage barley were started on April 23, in one of which the nutrient solution remained unchanged throughout the experiment, which concluded on June 16. In the two other sets the solution was renewed every two and three weeks respectively for the same period. All the experimental plants were taken from the same batch of seedlings, sown April 14, the seeds being graded between 0.05 and 0.06 gm. During the eight weeks of the experiment the differences between corresponding

728 *Action of Certain Metallic Compounds on Crops*

plants in the three sets were not usually very marked, except that in the unchanged series etiolation became evident and had to be rectified to the provision of additional ferric chloride. The controls were all satisfactory, the strongest being those in solutions with a three-weekly change, and the weakest with a fortnightly change (Fig. 7).

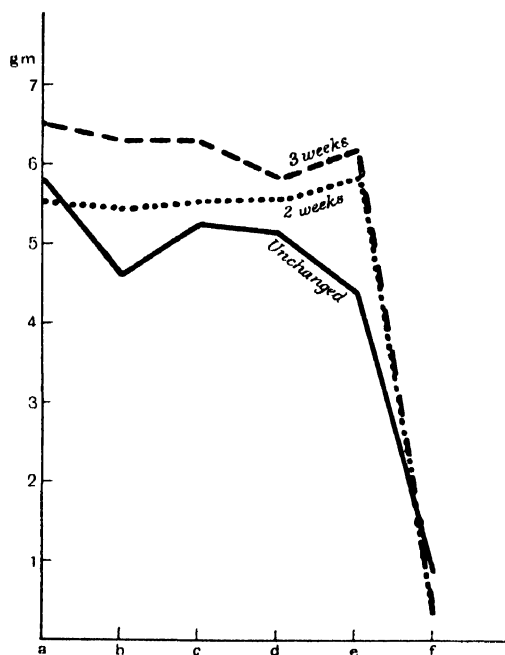


Fig. 7. Total dry weights of barley grown in nutrient solutions with aluminium sulphate, April 23–June 16. — Solutions never changed; solutions changed every 2 weeks. - - - - - solutions changed every three weeks.

- a, Control; no aluminium sulphate
- b, 0.733 : 100,000,000 aluminium sulphate
- c, 0.733 : 10,000,000 ,,
- d, 0.733 : 1,000,000 ,,
- e, 0.733 : 100,000 ,,
- f, 0.733 : 10,000 ,,

With 0.733 : 10,000 aluminium sulphate roots and shoots were badly checked, the shoots remaining small and much etiolated throughout, while the roots were short and bunchy, remaining above the surface of the solution for some time and then pushing out some longer, thick rootlets differing in type from the normal roots. The damage was obviously more severe where the solution had been renewed, doubtless owing to the additional supply of fresh toxic material brought into contact with the roots. This was further shown by the dry weights, which were considerably reduced by change of solution. With lower concentrations

of aluminium sulphate the general impression was that most of the plants were better than the controls, especially as regards the shoots. This, however, was not borne out by the dry weights, which were in some cases definitely lower than those of the controls, especially in the unchanged set. Statistical examination of the results by analysis of variance showed no evidence of stimulation by any concentration of aluminium sulphate, even when due allowance was made for a somewhat improved growth of the controls owing to reduction of competition by their position alongside small, badly poisoned plants. Toxic action was very evident with 0.733 : 100,000 in the unchanged set, was less marked when the solutions were changed every three weeks, and was hardly manifest with a fortnightly change. The best general growth, however, was obtained with a three-weekly change.

The result with the weakest concentration in the unchanged set was inexplicably low, otherwise the results from all three series fall into line when the standard error is taken into consideration, showing reduction of toxicity to a neutral concentration varying with the frequency of change of solution, but with no evidence of stimulation by any concentration down to 0.733 : 100,000,000 aluminium sulphate.

Peas.

Sutton's Harbinger, from seeds graded 0.3–0.35 gm. was grown from May 15 to June 28 in concentrations parallel to those of the barley described above, only the unchanged series being tested. In this case the strong 0.733 : 1000 solution was interpolated, but the roots were most seriously injured within three days, becoming white and flabby, and

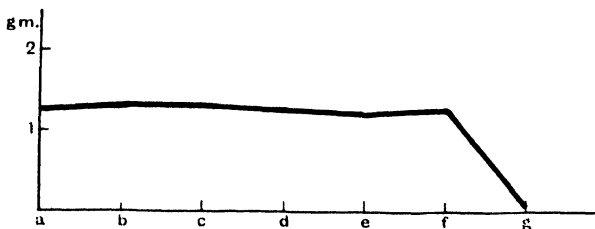


Fig. 8. Total dry weights of peas grown in nutrient solution with aluminium sulphate, May 15–June 28. Solutions never changed.

- a, Control; no aluminium sulphate
- b, 0.733 : 100,000,000 aluminium sulphate
- c, 0.733 : 10,000,000 ..
- d, 0.733 : 1,000,000 ..
- e, 0.733 : 100,000 ..
- f, 0.733 : 10,000 ..
- g, 0.733 : 1000 ..

730 *Action of Certain Metallic Compounds on Crops*

although a few abortive attempts were made to put out laterals above the surface of the solution the plants were quite dead and shrivelled long before the end of the experiment. In spite of the marked toxicity in this case, however, the next concentration (one-tenth as strong) had no adverse effect whatsoever, for although the plants looked as if they might be a trifle weaker than the controls, the dry weights were fully as good. Comparing this with barley under similar conditions it appears that peas are less sensitive to the poisoning action of aluminium, as they are unaffected by 0.733 : 10,000 aluminium sulphate, whereas barley is most seriously checked by this and is also somewhat depressed by one-tenth the concentration. With peas, also, there was not the slightest indication of stimulation during the early vegetative phase of growth, the dry weights being remarkably level for all concentrations tested (Fig. 8).

Maize.

The question arose as to whether the composition of the nutrient solution would influence the effect of aluminium sulphate on growth. Three solutions were therefore tested in parallel, the supply of nitrogen being the same in all solutions to avoid the second limiting factor which

Table X. *Total dry weights of maize after eight weeks' growth.*

Solution	A (gm.)	B (gm.)	C (gm.)
Control	3.92	3.97	3.83
0.733 : 100,000,000	4.08	3.10	3.34
0.733 : 10,000,000	3.45	2.85	3.79
0.733 : 1,000,000	4.12	3.17	4.01
0.733 : 100,000	3.16	2.58	4.31
0.733 : 10,000	1.24	2.68	1.87
0.733 : 1000	0.32	0.29	0.29

might be introduced by deficiency of this essential element. The same concentrations of aluminium sulphate were used as with peas and barley. Maize was used as the test plant grown from seed, and the solutions were changed once, for every solution, at the end of four weeks' growth. The experiment was concluded when the plants were two months old.

Solution	A (gm.)	B (gm.)	C (gm.)
Sodium nitrate	—	0.5	—
Potassium nitrate	1.0	0.2	1.0
Magnesium sulphate	0.5	0.1	0.25
Sodium chloride	0.5	0.1	0.04
Potassium di-hydrogen phosphate	0.5	0.1	0.25
Calcium sulphate	0.5	0.1	0.25
Ferric chloride	0.04	0.04	0.04
Distilled water to make up 1 litre			
pH	3.5	3.1	3.5

In spite of the acidity of the solutions the plants grew well, except in the strongest aluminium sulphate. 0.733 : 1000 allowed practically no growth, 0.733 : 10,000 was markedly toxic in all three solutions, but the toxicity of lower concentrations was doubtful, as the individual plant varied so much in development (Table X). The hydrogen-ion concentration of the solutions were as follows:

Aluminium sulphate. Nutrient solution			
	A	B	C
Control	3.5	3.0	3.5
0.733 : 100,000,000	3.5	3.0	3.5
0.733 : 10,000,000	3.5	3.0	3.5
0.733 : 1,000,000	3.5	3.0	3.5
0.733 : 100,000	3.3	3.0	3.5
0.733 : 10,000	3.1	3.0	3.1
0.733 : 1000	pH below 3.1	below 3.0	below 3.1*

* Most acid of all solutions.

The very toxic action of the strong aluminium sulphate would not appear to be associated with increased acidity, as in solution B controls grew well in a solution as acid as those which killed the plants in the presence of strong aluminium sulphate. It was rather surprising too that as good growth of the controls was obtained in the acid solution B as in the less acid A and C. With maize, as with peas and barley, no evidence of stimulation was found with any concentration of aluminium sulphate tested.

SUMMARY.

1. No beneficial effect on the growth of barley or mustard on two types of soil was obtained by the addition of quantities of *copper* sulphate ranging up to 4 per cent. of the total artificial fertilisers applied. Experiments on English acid and alkaline peats with barley, rye and turnips failed to show the striking results obtained by American workers on saw-grass peat in the Everglades of Florida.

2. Increased fineness of grinding of basic slag in some cases brings about a certain reduction of crop. This may be due to the presence of *vanadium* in such slags, as experiments show that this element is definitely toxic to plant growth.

3. *Lithium* compounds are much less toxic than copper to the growth of barley. In some water culture experiments a suggestion of stimulation was obtained with very dilute concentrations of lithium chloride in the presence of nutrient salts, paralleling Voelcker's results with other lithium compounds in soil. Buckwheat is much more sensitive to the

toxic action of lithium, and also shows no stimulation with any concentration.

4. Small proportions of *titanium* compounds, added to the usual artificial fertilisers, failed to improve the growth of mustard on two very different soils. The amount of lime present in the titanium compounds was insufficient to act beneficially on that soil for which dressings of lime were requisite in the ordinary course of cultivation.

5. Barley proved to be very sensitive to the toxic action of *aluminium* sulphate, the harmful effect becoming more evident when the nutrient solutions were renewed, so that fresh supplies of poison were brought into contact with the roots. Peas were much less affected, remaining quite healthy in concentrations which killed barley. The toxic action did not appear to be associated with increased acidity, as maize grew well in a control solution as acid as those which killed the plant in the presence of strong aluminium sulphate. No evidence of stimulation was obtained with either barley, peas or maize with any strength of aluminium sulphate, however dilute.

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(Received April 27th, 1932.)

[*Reprinted from the Journal of Ecology,*
Vol. XXI. No. 1. February, 1933.]
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THE WEED SEED POPULATION OF ARABLE SOIL

II. INFLUENCE OF CROP, SOIL AND METHODS OF CULTIVATION UPON THE RELATIVE ABUNDANCE OF VIABLE SEEDS

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(*With four Figures in the Text.*)

CONTENTS.

	PAGE
I. INTRODUCTION	103
II. BURIED WEED SEEDS IN WOBURN SOIL, UNDER CONTINUOUS WHEAT AND BARLEY	104
III. INFLUENCE OF METHODS OF CULTIVATION ON THE WEED SEED POPULATION OF SOIL	107
(1) Response of different species to identical fallowing	108
(a) Rothamsted wheat	108
(b) Woburn wheat and barley	114
(α) Effect of first year's fallow on Woburn wheat and barley land	115
(β) Comparison of effect of first year's fallow on Rothamsted and Woburn wheat soil	115
(γ) Recolonisation on Woburn soil during defective fallowing	116
(2) Response of different species to identical methods of crop cultivation	117
(3) Comparison of the effect of fallowing and crop cultivation on the seed population of the same species	120
(a) Species responding to cropping and fallowing in the same general direction	120
(b) Species responding irregularly to cropping and fallowing	125
IV. SUMMARY	126

I. INTRODUCTION.

In a previous number of this JOURNAL¹ an account was given of an attempt to make a quantitative estimate of the number of viable weed seeds buried in the soil of Broadbalk wheat field, Rothamsted, in 1925, the influence of manuring on the distribution and the relative lengths of dormancy of the various species

¹ **Brenchley, W.E.** and **Warington, K.** "The weed seed population of arable soil. I. Numerical estimation of viable seeds and observations on their natural dormancy." This JOURN. **18**, No. 2, 235-72, 1930.

also being considered. At that time the weed flora was so prolific as to be a serious menace to the wheat crop, which, for experimental reasons, has been autumn sown on the same area since 1843. A definite campaign against the weeds was therefore planned, but, as it was undesirable that any break in crop continuity should occur, it was decided to make an intensive attack on one part of the field by means of fallowing operations for two years, while the rest of the area was cropped and subjected to as thorough cultivation as was possible under the circumstances. At the end of the two years the process was reversed, but the fallowed portions were arranged to overlap, so that one part of the field remained without a crop for four years. At the same time a parallel experiment was carried out at Woburn on sandy soil on continuous wheat and barley plots to provide a comparison between the effects of fallowing on different types of soil. The data for this latter experiment are now available and, before proceeding to deal with the effects of fallowing operations, it is necessary to consider briefly the weed seed population of the Woburn soil at the beginning of the experiment, for comparison with the Rothamsted results set forth in the previous paper.

II. BURIED WEED SEEDS IN WOBURN SOIL, UNDER CONTINUOUS WHEAT AND BARLEY.

Stackyard field, Woburn, carried wheat and barley continuously from 1877 to 1926 inclusive, when the land had become so foul with weeds that it was decided to put it under bare fallow for two years. In 1929 the field was again under crop.

The wheat is always autumn-sown, necessitating autumn ploughing only, followed by cultivating and hoeing as occasion arises. The barley is always spring-sown, permitting both autumn and spring ploughing. So far as cultivation goes, the barley crop has allowed greater opportunities for the germination and destruction of weed seedlings, such as *Alchemilla arvensis*, *Cerastium vulgatum*, *Juncus bufonius*, *Matricaria inodora*, *Myosotis arvensis* and *Vicia hirsuta*. On the other hand, the wheat, established in the autumn and spreading its tillers early in the year, has probably reduced by competition some species that are able to grow and hold their own with spring-sown barley, such as *Capsella bursa-pastoris*, *Chenopodium album*, *Gnaphalium uliginosum* and *Veronica buxbaumii* (*V. polita* of preceding paper¹). To a less marked extent this reduction among wheat applies to the more abundant weed, *Spergula arvensis*. The relative abundance of the major weed species among the two crops is shown in Table I, all minor species, of which less than twenty appeared from the bulked samples in both crops, being omitted.

¹ Since the publication of the first paper, Dr Eric Drabble has examined specimens of the *Veronica polita*, which had been considered to be a probable hybrid between *V. polita* and *V. buxbaumii*, and we are indebted to him for his opinion that the species is in reality true *V. buxbaumii*. In future, therefore, the name *V. buxbaumii* will be used for this species.

Table I. *Woburn soil. Number of seedlings from buried seeds present before fallowing, all samples added together*. (8½ sq. ft. area.)*

	Wheat	Barley
Species predominant in wheat		
<i>Agrostis stolonifera</i>	181	86
<i>Alchemilla arvensis</i>	4,520	44
<i>Arenaria serpyllifolia</i>	84	6
<i>Cerastium vulgatum</i>	435	1
<i>Juncus bufonius</i>	339	8
<i>Legousia hybrida</i>	60	23
<i>Matricaria inodora</i>	3,183	234
<i>Myosotis arvensis</i>	87	—
<i>Papaver</i> spp.	131	4
<i>Poa annua</i>	2,816	1,314
<i>Veronica arvensis</i>	407	137
<i>V. hederæfolia</i>	48	1
<i>Vicia hirsuta</i>	130	—
<i>Viola arvensis</i>	116	13
Total	12,537	1,871
Species predominant in barley		
<i>Capsella bursa-pastoris</i>	255	1,520
<i>Chenopodium album</i>	7	162
<i>Gnaphalium uliginosum</i>	344	1,007
<i>Lamium amplexicaule</i>	70	185
<i>Polygonum aviculare</i>	1,041	1,316
<i>P. convolvulus</i>	10	30
<i>Rumex acetosella</i>	43	56
<i>Senecio vulgaris</i>	39	84
<i>Spergula arvensis</i>	8,475	16,110
<i>Stellaria media</i>	280	915
<i>Veronica buxbaumii</i>	14	860
Total,		
excluding <i>Spergula arvensis</i>	2,103	6,135
<i>Spergula arvensis</i>	8,475	16,110
Grand total	10,578	22,245

* Twenty-six barley soil samples, each 48 sq. in. area (8½ sq. ft.). Twenty-two wheat soil samples, each 48 sq. in. area (7½ sq. ft.). For purposes of comparison with barley the wheat weed seeds were recalculated for an area of 8½ sq. ft.

A further analysis of Table I shows very clearly how the weed flora associated with a particular crop is influenced by the correlation between the periodicity of germination of the various weed species and the method of cultivation and time of sowing of the crop (Table II).

Species with maximum germination in autumn are able to maintain their position with autumn-sown *wheat*, but are ruthlessly cut down, often before flowering, by the later ploughing and cultivating for the spring-sown *barley*. Those weeds that show no periodicity, and yet are chiefly associated with wheat, have generally some peculiarity which explains the distribution. *Matricaria inodora* is very impatient of competition and usually occurs in abundance only in thin places and at the edges of crops. The seedlings which appear with the wheat in autumn get well established and doubtless, on this sandy soil on which the wheat crop is not very heavy, they are able to hold their own when spring growth begins. With the barley crop, on the other hand, the *Matricaria* seedlings come into direct competition at a very early stage, and the species

has gradually been crowded out by the repeated growth of the same crop. With regard to *Agrostis*, *Vicia* and *Juncus*, it may be that a long growth period is needed before seed formation occurs, and that seeds have time to ripen with the wheat but are not fully developed by the time the spring-sown barley crop is harvested. *Poa* and *Arenaria* grow freely during the autumn and winter months, producing plants that with wheat are able to seed and restock the soil, but with barley are cut down by cultivation. Probably both species suffer from the competition of a strongly growing cereal crop, so that in spite of their ability to germinate throughout the year, comparatively few plants are able to establish themselves from seeds which start into growth in the spring.

Table II. *Periodicity of germination of major weed species.*

A. Species dominant in wheat.	
Maximum germination in <i>autumn</i> *	No peak season for germination
Alchemilla	Agrostis
Cerastium	Arenaria
Legousia	Juncus
Myosotis	Matricaria
Papaver	Poa
Veronica arvensis†	Vicia
V. hederæfolia	
Viola	
B. Species dominant in barley.	
Maximum germination in <i>winter and spring</i>	No peak season for germination
Polygonum aviculare	Capsella
P. convolvulus	Chenopodium
	Gnaphalium
	Lamium
	Senecio
	Spergula
	Stellaria
	Veronica buxbaumi†

* For convenience of reference autumn implies October–December, winter implies January–March, spring implies April–June, summer implies July–September.

† At Rothamsted also *Veronica arvensis* and *V. hederæfolia* are correlated with continuous wheat, and *V. (buxbaumii) polita* with continuous barley.

The species dominant with *barley* are equally definite. No dominant weeds occur whose maximum germination is in autumn, as the bulk of their seedlings are cut down before the crop is sown. *Polygonum aviculare* and *P. convolvulus* are late germinating species, plentiful in both crops, but probably somewhat reduced in wheat by competition due to the greater development of the crop at the normal time of germination of the weed. The species with no definite periodicity are less easy to account for, unless it is they are more susceptible to competition at the time that the wheat is covering the ground with its tillers, while the barley is yet too small to be a serious competitor. In this case there is no definite, clean-cut factor, such as ploughing, to cause a sweeping reduction of any species among wheat as compared with barley, and this is shown by the number of weed seeds present on equal areas. Whereas the species

dominant in wheat gave 12,537 seedlings in wheat against 1,871 in barley, those dominant in barley gave 6,135 in barley against 2,103 in wheat, *Spergula* being omitted in both cases.

It is advisable to exclude *Spergula* in making the comparison, as it is so abundant in both crops that it swamps the other species collectively, and might be suspected of masking the true result. This, however, is not the case, as no alteration is brought about by its inclusion.

III. INFLUENCE OF METHODS OF CULTIVATION ON THE WEED SEED POPULATION OF SOIL.

Soil samples were taken annually, both at Rothamsted and Woburn, the procedure and method of after-treatment being fully described in the previous paper (pp. 238–40). Complete data for the Rothamsted area are now available as to the effect of the first and second years' fallowing as contrasted with the improved cultivation of the cropped portion. In the case of Woburn the whole field was put under fallow, so no comparison with crop cultivation is possible, attention being therefore confined to the results of fallowing. From the ecological point of view the interest lies in the varying response of the different species to the two forms of human interference with their natural habitat.

When land is deliberately left fallow in order to reduce weed infestation, the chief aim is to encourage germination of the buried weed seeds, and to cut down the seedlings before any have developed far enough to flower and produce more seed to re-infest the soil. This entails repeated working of the ground at intervals which vary according to the seasonal conditions prevailing. At the same time, these cultivations tend to bring fresh supplies of seed nearer to the surface and into conditions favourable for germination. It has become evident that the *crux* of the situation lies in the length of time between cultivations; since for certain weeds, under certain seasonal conditions, the period of safety is far less than is usually reckoned. For a clearer understanding of this point in its relation to individual species, it may be useful to summarise here (Table III) the processes of cultivation on the cropped and fallowed parts of Broadbalk Field at Rothamsted during this period of the experiment. Table III has general reference to sections 1, 2 and 3, in conjunction with which it should be read.

The numbers of viable seeds vary so greatly, both from species to species, and from plot to plot for any one species, that it is difficult to follow the trend of events if the actual totals only are considered. For purposes of comparison these total figures have been recalculated to a basis of 100 of the seeds present in the soil at the beginning of the experiment, i.e. really on a percentage basis, but the actual figures are also given in any tables utilised.

The experiment under discussion provides data as to the varying response of different weed species to identical fallowing treatment, and also affords a comparison of the effect of cropping and fallowing on the same species. For

the sake of clarity these two points will first be dealt with separately and summarised together at a later stage.

Table III. *Broadbalk Field cultural operations, 1925-7.*

1925	Fallowed, top three-fifths	1925	Cropped, bottom two-fifths
Oct. 28- Nov. 13	Ploughed	Oct. 28- Nov. 13	Ploughed with tractor
		Nov. 24	Drag harrowed
		Nov. 25	Wheat drilled, harrowed after
1926		1926	
Feb.	Furrows turned back	March 17	Began to harrow out grass
April 20	Disc harrowed	April 15	Hoeing begun with "Planet" cultivator and continued when possible
May 25, 26	Disc harrowed both ways		
June 1	Cross cut with path hoe (like a broadshare)	June 3	Thistles pulled up after rain
June 15, 19	Cross ploughed (horses)		
July 26, 31	Tractor cultivated both ways		
Aug. 4	Thistles cut with thistle bar and tractor	Aug. 26	Wheat cut
Aug. 5	Harrowed		
Sept. 29- Oct. 4	Ploughed landways	Sept. 9	Wheat carted
Oct.	Thistles cut	Sept. 29- Oct. 4	Ploughed
		Oct. 8	Worked down and wheat drilled
1927		1927	
Feb. 1	Cross-ridged, completed March 3		
March 29	Started splitting ridges, com- pleted April 6	March 22	Wheat harrowed
May 14	Split ridges again, completed May 17	April 21	Horse hoed
May 20	Harrowed down ridges, com- pleted May 23	May 5	Began hand hoeing
June 23	Ploughed across the plots and finished July 9		
Aug. 4, 5	Disc harrowed	Aug. 26-27	Wheat cut
Aug. 6	Thistles cut with thistle bar and tractor		

(1) *Response of different species to identical fallowing.*

(a) *Rothamsted wheat.*

The effect of fallowing on the weed seed population of the soil is really the result of a single factor, i.e. human interference with seedlings which have not been allowed to flower and develop seeds. If fallowing is efficiently carried out every germinating seed is put out of action, and the degree of reduction depends upon the proportion of the seed population which is brought into a favourable position for germination during the process of cultivation. The seeds which are still in a naturally dormant condition will not germinate, even when thus favourably placed, and the varying response of different weed

species to fallowing is chiefly due to the variation in their period of natural dormancy. If, however, fallowing is not properly carried out, or if the period between cultivations is too long, certain of the seedlings in some species may develop far enough to produce seeds which aid in re-stocking the soil, thus vitiating the beneficial effects of the fallow for those species.

The simplest way to demonstrate the very variable response of different species is to arrange them in numerical order of response per 100 seeds present before fallowing.

Table IV. *Number of viable buried seeds from equal areas in three successive years. (All seven plots together.)*

Land cropped 1925, fallowed 1926, 1927.

	Actual population per 21 sq. ft.			Relative population in percentages		
	1925	1926	1927	1925	1926	1927
Group A						
<i>Capsella bursa-pastoris</i>	222	243	216	100	109	97
<i>Arenaria serpyllifolia</i>	381	400	350	100	105	92
<i>Veronica buxbaumii</i>	117	123	75	100	105	64
Group B						
<i>Veronica hederifolia</i>	916	712	375	100	78	41
<i>Papaver rhoeas</i>	44,564	28,143	20,489	100	63	46
Group C						
<i>Matricaria inodora</i>	127	67	45	100	53	35
<i>Linaria minor</i>	201	105	54	100	52	27
<i>Legousia hybrida</i>	658	322	250	100	49	38
<i>Euphorbia exigua</i>	353	172	35	100	49	10
<i>Veronica arvensis</i>	3,221	1,541	687	100	48	21
<i>Alchemilla arvensis</i>	5,658	2,463	1,799	100	43	32
Group D						
<i>Bartsia odontites</i>	128	51	41	100	40	32
<i>Sonchus arvensis</i>	125	47	24	100	38	19
<i>Myosotis arvensis</i>	774	281	135	100	37	17
<i>Caucalis arvensis</i>	275	101	41	100	37	15
Group E						
<i>Galium tricornu</i>	66	20	6	100	30	9
<i>Atriplex patula</i>	452	130	53	100	29	12
<i>Polygonum convolvulus</i>	42	12	1	100	29	2
<i>Senecio vulgaris</i>	372	103	28	100	28	7
<i>Ethusa cynapium</i>	283	70	23	100	25	8
<i>Medicago lupulina</i>	153	38	10	100	25	7
<i>Polygonum aviculare</i>	1,130	275	43	100	24	4
<i>Anagallis arvensis</i>	95	22	26	100	23	27
<i>Alopecurus agrestis</i>	5,440	1,224	240	100	22	4
<i>Scandix pecten</i>	604	111	20	100	18	3
<i>Stellaria media</i>	104	16	11	100	15	11
<i>Galium aparine</i>	243	34	20	100	14	8

The species are arranged in order of the reduction undergone during the first year's fallowing. Those in heavy type in the last column are species which behaved abnormally for their group in the second year's fallowing.

After a single year's fallowing the remaining viable seeds present varied from 109 per cent. to 14 per cent. of the original numbers, a second year's fallowing reducing these to from 97 per cent. to 2 per cent. The further reduction in the second year averaged about 20 per cent., with a few noteworthy

exceptions, which are clearly seen if the species are grouped, as in Tables IV and V.

Table V. *Summary of effect of fallowing on percentage of buried weed seeds.*

After one year's fallow		After two years' fallow	
Group A.	Over 100%	100-90 %	except <i>Veronica burbaumii</i>
		64 %	
" B.	" 61-80 %	41-50 %	
" C.	" 41-60 %	21-40 %	except <i>Euphorbia exigua</i>
		10 %	
" D.	" 31-40 %	13-20 %	except <i>Bartsia odontites</i> 32 %
" E.	" 10-30 %	12 % and below	except <i>Anagallis arvensis</i> 27 %

Group A. The most unexpected result was the behaviour of *Capsella*, *Arenaria* and *Veronica burbaumii* in keeping up their numbers in spite of the frequent disturbance of the soil, but an adequate reason is revealed by a correlation of the habits of the species and the cultural operations carried out. *Arenaria* and *V. burbaumii* are characteristically trailing species that begin to flower and fruit at a very early stage, comparatively soon after germination. As they continue flowering over a long period the soil is freely replenished with seed. The importance of the insignificant, earliest formed flowers has never yet been fully appreciated, but it is now becoming evident that this neglected habit is at the bottom of many failures to reduce weeds by methods of cultivation. *Capsella* is not obviously of the same type, but under certain conditions it behaves very similarly. Many plants will produce large rosettes of leaves and delay flowering till they are thoroughly well established. On the other hand, search among *Capsella* colonies, particularly during the winter months, reveals numerous tiny plants, perhaps only half an inch high, flowering and producing seed at a very early stage in their life history. In the previous paper¹ it has already been shown that these three species germinate freely during the winter months. *Capsella* germinates readily all the year round with a certain maximum in the spring, *Veronica burbaumii* also germinates at any time, without any peak period, whereas *Arenaria* comes up freely in winter and spring, very few seedlings appearing in the summer. An examination of Table VI shows various undisturbed periods when the land was under fallow during which it would have been possible for these species, with their particular habits of growth and germination, to replenish the soil with seed.

It is probable that the danger point for these species is the long slack period from October or November to March or April, when those in charge of farm operations would not be expecting that any plants would be sufficiently active in seed formation to do any damage.

The winter period, October to April, was particularly favourable in 1925-6, as the mean temperature in every month exceeded the average of that for the 53 years 1878-1930 (Table VII). The following winter the mean temperature

¹ Brenchley, W. E. and Warington, K., This JOURNAL 18, No. 2, 235-72, 1930.

equalled the average, and the relative mildness of both seasons was doubtless favourable to the germination and growth of the species under discussion.

Table VI. *Fallowing operations on Broadbalk Field.*
Intervals between cultivations.

1st year	Nov. 13, 1925–Feb. 1 (or later), 1926	...	...	80 days at least
	Feb. 15 (approx.)–April 20...	...	...	64 days approx.
	April 20–May 25	...	...	35 days
	June 19–July 26	...	...	37 days
2nd year	Oct. 4, 1926–Feb. 1, 1927	...	...	120 days
	March 29–May 14	...	...	46 days
	June 23–Aug. 4	...	...	42 days

Table VII. *Mean monthly temperatures.*

	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	Mean
1925–6	50.3	43.9	42.1	38.2	44.0	43.2	48.0	44.2
1926–7	50.3	38.8	36.3	38.7	38.1	44.6	45.8	41.8
Average 1878–1930	48.7	42.1	38.5	37.5	38.5	41.1	45.4	41.7

The reduction in *Veronica buxbaumii* which occurred after the second year's fallow may be associated with its very short period of natural dormancy. Under favourable conditions practically all the seeds will germinate at once, and if a high germination happened to be induced shortly before a cultivation the number of potential seed producers would be greatly reduced, without others being in waiting to take their place. This may also have happened sometimes during the 1926–7 season, but as *Capsella* and *Arenaria* have much longer periods of natural dormancy, preventing such a large proportion of seeds from germinating at once, this particular factor would not operate to reduce them to the same degree.

Group B. Veronica hederifolia is another trailing species which begins to form fruit at a very early stage. Under normal conditions its germinating period is practically confined to the autumn, and a fair proportion of seeds appear to have a period of more than three years' natural dormancy. The marked autumn periodicity, coupled with the slackness in cultivation during the winter months, obviously permitted a certain amount of re-stocking of the soil with seeds, thus accounting for the comparatively small reduction to 78 and 41 per cent. effected by fallowing from year to year.

Papaver rhæas comes in an entirely different category, as flowering and seed production is always delayed till late spring or early summer, although seeds may germinate freely from autumn to spring according to climatic conditions. This habit of flowering subjected *Papaver* to the full force of spring and summer cultivation, so that no opportunity occurred for re-stocking the soil with fresh seed. The slow reduction to 46 per cent. in two years effected by fallowing in this case must therefore be attributed to the long period of natural dormancy in this species. Under experimental conditions in germination pans, where a small volume of soil is thoroughly turned over eight times a year,

poppies are still germinating at the present time (1931) in samples taken in August, 1925. This fully accounts for the failure of even prolonged fallowing to bring about any adequate reduction of poppies on badly infested land, as the remaining seeds which gradually emerge from dormancy very soon recolonise the land, owing to the prolific seed production per plant. From the practical point of view it is evident that fallowing is an uneconomic means of eradicating poppies, and other methods need to be sought to combat them.

Group C. The species in this group, except *Euphorbia exigua*, show a medium response to fallowing, about one-third of the original seed stock being left after two years' treatment. *Legousia*, *Linaria* and *Matricaria* are all species which delay flowering until spring or summer and are therefore affected by cultural operations. The relatively long period of dormancy in *Legousia* and *Matricaria*, as contrasted with the short period in *Linaria*, is reflected in the difference in the ultimate reduction of the three species to 38, 35 and 27 per cent. respectively.

Alchemilla and *Veronica arvensis* are more difficult to reconcile with this group, as they might have been expected to be more resistant to the influence of fallowing. Both germinate chiefly in autumn, both are of the trailing habit which may begin to fruit before spring cultivation becomes active, and both have relatively long periods of natural dormancy, all of which are factors tending to keep up the seed population of the soil. Closer observation of the habits of these two species in the field is needed, as it is possible that in spite of their habit they may delay flowering till spring or summer, or may be unable to ripen seed from the earliest formed flowers. The discrepancy in behaviour between the three species of *Veronica* is very marked, *V. arvensis* being so reduced by fallowing that it is almost on the border line of the lower group D.

Euphorbia exigua is the one member of this group which shows further rapid response during the second year's fallowing, being reduced to 10 per cent. of the original population. This is probably associated with the very short period of natural dormancy of the majority of seeds of this species, coupled with the habit of summer flowering. It is recognised (previous paper, p. 256) that *E. exigua* tends to be irregular in its habit of germination, which may be delayed so as to give a bigger rush of seedlings in the second year than in the first from the same samples of soil. It would therefore be unwise to assume that the drastic reduction here recorded would always occur with this species under similar treatment in different seasons. Further information on this point will probably emerge from the present experiment as time goes on.

Group D. Species in groups D and E, with the solitary exception of *Bartsia odontites*, may be regarded as being effectively reduced by fallowing operations.

Sonchus, *Myosotis* and *Caucalis* are all spring or summer flowering, with a fairly wide periodicity of germination, and the two former have only short periods of natural dormancy. *Caucalis* is very efficiently reduced considering that its natural dormancy is rather long.

Bartsia odontites, in spite of its heavy reduction during the first year, was little affected in the second season. This was surprising in view of the apparent short period of natural dormancy determined during the preliminary experiment, but there is now some evidence from later observations that *Bartsia* is erratic in its germination and may vary in the length of its natural dormancy. If so, it may have happened that seasonal conditions during the second year of fallowing were unfavourable to the germination of this species and that most of the seeds remained dormant, keeping up a relatively high level of soil population. Under other seasonal conditions *Bartsia* might have come into line with the other species of this group.

Group E. Nearly half of the more abundant weeds fall into this category, including some of the most troublesome species, such as *Alopecurus*. The peak period of germination varies considerably within the group, but with the two exceptions of *Stellaria* and *Senecio* all are plants which normally flower in spring and summer and are, therefore, open to influence by cultivation. In the majority of cases the period of natural dormancy is short, and this fact, coupled with the incidence of flowering, results in a fairly complete clearance of viable seeds from the soil during two years' continuous fallow.

Anagallis arvensis is the only species in which no further reduction was effected by the second year of the fallow, which was doubtless partly due to the long period of natural dormancy preventing so thorough a clearance. Some other factor also appears to have operated here, as this is the only instance where no reduction at all occurred in 1927. The possibility exists that seasonal conditions in this year were very favourable to the rapid germination and growth of *Anagallis*, so that it was able to set seed and replenish the soil in the interval between cultivations, particularly from March 29th to May 14th. The records, however, show nothing abnormal in the weather conditions at this time, as average conditions of temperature, rainfall and bright sunshine were prevailing. Soil replenishment might also have happened between June 23rd and August 4th, except that summer germination is abnormal, though some climatic factor might have induced it on this occasion. Though average temperatures prevailed, this period was very deficient in bright sunshine and the rainfall was rather above the mean for 78 years, which may have been a combination of circumstances favourable to this species.

Stellaria and *Senecio* will germinate freely all the year round, though *Senecio* tends to a maximum peak in spring. Both plants, likewise, flower and fruit to some extent at all seasons, but the seeds have very short periods of natural dormancy. Consequently when a good seed bed is produced by fallowing the bulk of the seeds germinate soon after they are shed, and as this happens more rapidly during the spring and summer the numbers destroyed by cultivation far exceed those replaced in the soil during the slack winter period. The short period of dormancy is the critical factor, as with constant cultivation and induced rapid germination, relatively few seeds are left to carry out recolonisa-

tion, and this much more than counter-balances the number added by winter flowering plants.

(b) *Woburn wheat and barley.*

It was originally intended to treat these plots in exactly the same way as at Rothamsted and to fallow them intensively for two seasons, but owing to unavoidable circumstances no cultivations were carried out between January and July in the second year. This to a large extent minimised the value of the fallow from an agricultural point of view, but provided a most practical object lesson on the rapidity with which certain species will recolonise cleared land, unless active repressive measures are maintained against them. The longest intervals between the cultivations of the Woburn barley plots are set out in Table VIII, those for wheat being much the same, varying by a few days only.

Table VIII. *Fallowing operations in Stackyard Field, Woburn. Prolonged intervals between cultivations on barley plots.*

March 10–May 17, 1927	...	...	...	68 days
August 22–November 2, 1927	...	...	...	72 days
January 9–July 6, 1928	...	...	...	179 days

Table IX. *Number of viable weed seeds from equal areas in three successive years (Woburn). (All plots together.)*

	Land cropped 1926; fallowed 1927, 1928.											
	Actual population per 8½ sq. ft.						Relative population in percentages					
	Wheat			Barley			Wheat			Barley		
	1926	1927	1928	1926	1927	1928	1926	1927	1928	1926	1927	1928
Group A												
Myosotis arvensis	87	103	39	—	1	—	100	118	45	—	—	—
Alchemilla arvensis	4,520	4,197	3,271	44	11	27	100	93	72	100	25	61
Papaver spp.	131	110	70	4	12	12	100	84	53	—	—	—
Group B												
Legousia hybrida	60	41	24	23	34	13	100	69	39	100	148	57
Veronica hederifolia	48	30	95	1	—	3	100	61	195	—	—	—
Group C												
Viola arvensis	116	67	52	13	16	13	100	58	45	—	—	—
Arenaria serpyllifolia	84	47	65	6	3	8	100	56	77	—	—	—
Veronica arvensis	407	200	161	137	12	28	100	49	40	100	9	20
Spargula arvensis	8,475	3,967	3,470	16,110	7,389	4,767	100	47	41	100	46	30
Matricaria inodora	3,183	1,462	1,216	234	99	63	100	46	38	100	42	27
Agrostis stolonifera	181	79	143	86	41	131	100	44	79	100	48	152
Juncus bufonius	339	145	427	8	2	25	100	43	126	—	—	—
Group D												
Gnaphalium uliginosum	344	110	96	1,007	106	190	100	32	28	100	11	19
Group E												
Cerastium vulgatum	435	125	181	1	—	2	100	29	42	—	—	—
Poa annua	2,816	720	771	1,314	396	1,019	100	26	27	100	30	78
Stellaria media	280	72	158	915	335	435	100	26	57	100	37	48
Vicia hirsuta	134	32	38	—	—	—	100	24	28	—	—	—
Veronica buxbaumii	14	12	9	860	228	211	—	—	—	100	27	25
Capsella bursa-pastoris	255	33	70	1,520	523	535	100	13	27	100	34	35
Rumex acetosella	43	4	7	56	2	2	100	8	17	100	4	4
Senecio vulgaris	39	2	4	84	17	28	100	6	9	100	20	33
Larnium amplexicaule	70	4	8	185	50	32	100	5	12	100	27	17
Polygonum aviculare	1,041	37	119	1,318	42	104	100	4	11	100	3	8
Chenopodium album	7	—	1	162	25	34	—	—	—	100	15	21

In Table IX the Woburn weed species are arranged in the order in which they were affected by the first year's fallowing on the wheat land, which carried more weeds than the barley soil, *Spergula* being excluded. For convenience of reference the species are grouped according to the percentage of buried seeds remaining at the end of the year, as follows:

Group A. Over 80 %	Group C. 41-60 %
„ B. 61-80 %	D. 31-40 %
Group E. 0-30 %	

These groups correspond to those on Rothamsted soil, except that group A ranges from 80 per cent. instead of 100 per cent. upwards, and group E extends below the 10 per cent. of the parallel Rothamsted group.

The comparisons emerging from this table are dealt with under the following headings, (α), (β) and (γ).

(α) *Effect of first year's fallow on Woburn wheat and barley land.* Several species which are prominent on the wheat plots are either absent from the barley plots or are there present in such small numbers that the percentage figures are entirely meaningless and are therefore omitted. Only with *Chenopodium album* and *Veronica buxbaumii* did the reverse position occur.

In all species of which the seeds were initially present in any abundance the reduction due to fallowing was practically equal on the wheat and barley soil. *Spergula*, *Matricaria*, *Agrostis*, *Poa*, *Polygonum aviculare* and probably *Stellaria* come into this category, which also includes *Rumex acetosella* in spite of its small numbers. Wherever discrepancies occur it will be noticed that relatively few seeds were present on one or other of the soils, in which case the reduction was usually greater, as with *Alchemilla*, *Veronica arvensis*, *Capsella*, *Senecio* and *Lamium amplexicaule*. *Gnaphalium*, however, showed the greater reduction on the barley soil which originally contained the most seeds, and with *Legousia* there was a reduction on the wheat soil and an increase on the barley soil, which is not easy to explain.

(β) *Comparison of effect of first year's fallow on Rothamsted and Woburn wheat soil.* At Rothamsted fallowing operations began with the first ploughing in October, but at Woburn the land was left untouched until January, a procedure which had a marked influence on the comparative reduction of certain species. At Rothamsted *Capsella*, *Arenaria* and *Veronica buxbaumii* reaped the advantage of the long quiescent winter period which afforded opportunity to restock the soil, and these species were able at least to maintain their position in spite of the later cultivation. At Woburn, after the initial samples were taken in January, no such opportunity offered during the first year of fallowing, and considerable reduction occurred, especially with *Capsella* and *Veronica buxbaumii*. The late ploughing had a reverse effect on *Alchemilla*, which is specifically an autumn-germinating species, with the result that far fewer seeds in proportion germinated at Woburn, and the reduction by fallowing was comparatively small. *Myosotis* is also largely an autumn-germinating species, heavily

reduced at Rothamsted and apparently unaffected at Woburn. No weight must be placed on the percentage increase on Woburn wheat, as the actual number of seeds was small enough to be seriously affected by the inevitable large experimental error. With all other species the response to fallowing was of the same order on the two areas, the variations being easily accounted for by the difference in the fallowing operations coupled with the probable variation in the rate of germination of any one species on the different soils under somewhat different climatic conditions.

(γ) *Recolonisation on Woburn soil during defective fallow.* An analysis of Table IX (given in Table X) shows that the weed species fall into three classes, according to their reaction to the conditions of the defective fallow from August, 1927 to July, 1928. The first of these classes in which the reduction was continued in the second year is quite distinct, but the other two overlap to some extent, as *Gnaphalium*, *Poa* and *Capsella* showed an increase on one soil but were not influenced by the fallowing on the other. In reality these two latter classes could be merged, as the fact that a species shows no reduction implies that some measure of recolonisation must have occurred to provide seeds to replace those eliminated by the fallowing operations. This would apply to *Vicia*, *Chenopodium* and *Veronica burbaumii*, but the numbers of *Rumex acetosella* after fallowing were too small to consider seriously.

Table X. *Results of second year's fallow on Woburn soil compared with position after first year's fallow¹.*

Decrease	No significant effect	Increase
<i>Myosotis</i>	—	<i>Veronica hederifolia</i>
<i>Alchemilla</i>	—	<i>Arenaria</i>
<i>Papaver</i>	—	<i>Agrostis</i>
<i>Legousia</i>	—	<i>Juncus</i>
<i>Viola</i>	<i>Gnaphalium</i> (on wheat)	<i>Gnaphalium</i> (on barley)
<i>Veronica arvensis</i>	—	<i>Cerastium</i>
<i>Spergula</i>	<i>Poa</i> (on wheat)	<i>Poa</i> (on barley)
<i>Matricaria</i>	<i>Vicia</i>	<i>Stellaria</i>
<i>Lamium</i>	<i>Veronica burbaumii</i>	—
—	<i>Capsella</i> (on barley)	<i>Capsella</i> (on wheat)
—	<i>Rumex acetosella</i>	<i>Senecio</i>
—	<i>Chenopodium</i>	<i>Polygonum aviculare</i>

Without exception the species in the first column, showing continued decrease due to fallow, comprise those which germinate freely in the early autumn under favourable conditions, and which would therefore have sprung up rapidly after the August ploughing in 1927. The November cultivation cut these down, and the later plants which appeared during the following spring did not ripen sufficient seed to make good the autumn loss. In the case of *Myosotis*, *Alchemilla*, *Papaver* and *Veronica arvensis* some measure of recolonisation doubtless occurred, as the reduction by fallowing was less than under Rothamsted conditions. This was probably also the case with *Spergula*,

¹ For convenience, species are left in the order in which they occur in Table IX, instead of being arranged in alphabetical order.

Viola and *Lamium*, for which no comparative figures are available. *Legousia* and *Matricaria*, on the other hand, are late in flowering, and may have been cut down by the July cultivation before they had ripened seeds, since they were as greatly reduced as at Rothamsted.

The species showing increase after the second year's fallowing were types without any marked periodicity of germination, with the exception of *Veronica hederæfolia* and *Polygonum aviculare*. The proportion of seeds germinating in early autumn and eliminated by the November ploughing was much smaller than in the group considered above, and therefore a relatively heavy crop of weeds appeared the following spring. All the species would be seeding freely before the July cultivations, the supplies of fresh seeds being in excess of those destroyed by the November ploughing, causing an increase in the soil population. The tendency of seeds of *Polygonum aviculare* to germinate chiefly in the early months of the year brings it into this category, but it is very difficult to explain the increase in *Veronica hederæfolia*, as this is typically an autumn-germinating species, which would normally have been seriously depleted by the November cultivation. Since the numbers of this weed were quite small, little weight should be placed on this isolated discrepancy, which may be affected by experimental error, accentuated with scattered species.

(2) *Response of different species to identical methods of crop cultivation.*

When land is cropped the factors influencing the weed seed population are far more complex than when it is under fallow, as the demands of the crop and the type of season become of great importance, since they have a direct bearing on the question of deliberate human interference from the point of view of weed reduction. With autumn-sown wheat late ploughing is impossible, and large numbers of weed seeds which would be brought to the surface during a year of fallowing remain in a condition of dormancy, buried too deeply for germination. The fate of the seeds which do germinate depends upon many factors. From wheat drilling to the first spring harrowing a period of four or five months elapses, during which large numbers of seeds germinate, some of which produce seedling plants within that time. Others become so well established along the drills that nothing but hand-pulling will remove them, a process that is impracticable under modern field practice. Hand or "Planet" hoeing from April onwards reduces the number of plants between the drills, but it is the season which determines whether the weeds have already scattered seed, whether they are cut down before they are sufficiently developed to produce seed, or whether large numbers of fresh seedlings appear after hoeing and remain undisturbed to replenish the weed seed population before harvest time. The natural dormancy of a species is therefore of less immediate importance when land is cropped, as it is outweighed by the effect of other factors. It remains, however, a vital point with regard to future years, as it enables a species to have a reserve of viable seed even after a season so un-

favourable that fresh seed formation has been at a minimum. This affords one explanation of the apparent reappearance of a weed in quantity after it has been negligible for some time.

The natural result of the interaction of so many factors is that conditions which encourage some species and lead to a heavy increase in the seed population are adverse to others. As the conditions vary from year to year, the balance between the species alters, and in no two successive seasons can the weed population be expected to present a similar quantitative composition. If a species is abnormally abundant in any season, so that it stocks the soil heavily with its seeds, it is quite probable that it will be relatively abundant in the immediately succeeding years, though this does not necessarily always happen. The variation from year to year is rather difficult to follow from the actual number of weed seeds present on a given area, and can most easily be studied by comparing the relative numbers present during the experimental years for every hundred that were originally in the soil at the beginning.

Table XI. *Number of viable buried seeds from equal areas in three successive years (Rothamsted). (All seven plots together.)*

Land cropped throughout 1925, 1926, 1927.

	Actual population 14 sq. ft.			Relative population in percentages		
	1925	1926	1927	1925	1926	1927
<i>Sonchus arvensis</i>	32	99	54	100	305	167
<i>Myosotis arvensis</i>	134	295	349	100	219	261
<i>Matricaria inodora</i>	18	40	20	100	218	109
<i>Medicago lupulina</i>	87	169	73	100	207	80
<i>Veronica arvensis</i>	942	1,909	1,204	100	202	127
<i>Veronica buxbaumii</i>	84	217	361	100	172	286
<i>Galium tricornue</i>	15	20	16	100	135	109
<i>Alopecurus agrestis</i>	4,792	6,329	6,562	100	133	137
<i>Arenaria serpyllifolia</i>	236	249	269	100	105	114
<i>Papaver rhœas</i>	46,183	40,227	39,078	100	87	85
<i>Galium aparine</i>	116	97	228	100	83	196
<i>Alchemilla arvensis</i>	3,632	2,850	2,720	100	79	75
<i>Senecio vulgaris</i>	266	196	96	100	73	36
<i>Veronica hederæfolia</i>	561	391	296	100	70	53
<i>Anagallis arvensis</i>	54	36	24	100	66	44
<i>Stellaria media</i>	103	63	29	100	61	28
<i>Capsella bursa-pastoris</i>	220	133	307	100	60	140
<i>Polygonum convolvulus</i>	49	26	9	100	53	18
<i>Euphorbia exigua</i>	165	84	21	100	51	13
<i>Caucalis arvensis</i>	75	39	80	100	51	107
<i>Atriplex patula</i>	374	168	124	100	45	34
<i>Æthusa cynapium</i>	127	43	36	100	34	19
<i>Logousia hybrida</i>	516	176	168	100	34	33
<i>Polygonum aviculare</i>	561	177	44	100	32	8
<i>Bartsia odontites</i>	130	36	20	100	27	16
<i>Linaria minor</i>	343	36	55	100	11	16
<i>Scandix pecten</i>	354	35	16	100	10	5
Total (excluding <i>Papaver</i>)	13,986	13,913	13,181	100	99	94

Table XI shows the actual number of viable seeds of the twenty-seven major species that germinated from all the samples, totalling 14 sq. ft. in area, taken from the cropped part of the plots during three successive experimental years. The number of poppy seeds always exceeded the aggregate of the rest of the species to such an extent that it has been necessary to consider them separately and to omit them in making comparisons between the other species.

Papaver showed the considerable decrease of 13 per cent. in 1926, but remained constant the next year. This first decrease may have been due to particular care being taken with the spring hoeing, with the deliberate intention of cutting down the poppy seedlings at the most vulnerable stage, since poppy was one of the chief weeds against which reduction measures were being directed. The total number of viable seeds of all other species was remarkably constant, showing hardly any change in 1926, and only being reduced to 94 per cent. of the original in 1927. Although the total number varied to such a small extent, very considerable fluctuations occurred for each species from year to year.

Calculation of the figures to a basis of every hundred present in 1925, representing the initial condition of the field, renders it possible to show the degree of increase or decrease in succeeding years for individual species. In the first season nine species showed increase, *Sonchus* being tripled, and *Myosotis*, *Matricaria*, *Medicago* and *Veronica arvensis* being doubled in quantity. The remaining seventeen species were reduced in varying degrees, *Linaria* and *Scandix* only persisting to the extent of about 10 per cent. of their original number.

In the 1927 season four of the leading weeds, *Sonchus*, *Matricaria*, *Medicago* and *Veronica arvensis* showed an average reduction of 50 per cent. and only two, *Myosotis* and *Veronica buzbaumii*, were significantly increased. On the other hand, among those weeds which were heavily reduced in 1926, *Galium aparine*, *Capsella* and *Caucalis* were more than doubled, while *Senecio*, *Euphorbia*, *Stellaria*, *Polygonum aviculare* and *P. convolvulus* were further reduced by more than one-half of their surviving number in 1926. These wide fluctuations are obviously correlated with the season, habit of growth of individual species, the time and thoroughness of cultivation, and the degree of crop competition, and studies on individual species would be necessary to ascertain with any accuracy the nature of this correlation. With an early season and late cultivation considerable increase might be expected in those species which germinate in autumn or very early spring, as they have time to mature many seeds before they are interfered with. On the contrary, a late season and early cultivation might allow the escape of those species which germinate most freely in spring, since more seedlings would come up after the hoeing and be able to recolonise the soil with seeds if they were able to withstand the competition of the crop. In an attempt to reduce annual weeds while the land is under crop, it seems probable that the greatest measure of success is associated with

two or more cultivations of which one is early and one fairly late in the season, as by this means a wide range of species is attacked at vulnerable periods. This is indicated in the present case. In 1926 harrowing began on March 17th, and hoeing on April 15th. This lapse of one month, without any later cultivation, was insufficient to bring about any significant reduction in the total number of buried seeds per unit area, although the numerical balance of species was altered. In 1927 cultivation was more thorough, with harrowing on March 22nd, horse hoeing April 21st, and hand hoeing May 5th. This third later cultivation was possibly the factor which aided in the reduction of the total weed seeds to 94 per cent. of the original supply.

(3) *Comparison of the effect of fallowing and crop cultivation on the seed population of the same species.*

The curves in Figs. 1-4 are derived from the relative populations given in Tables IV and XI. They represent the number of weed seeds, for every hundred originally present, that were found in the soil during 1926 and 1927 on fallowed and on cropped areas. To a certain extent the different species can be grouped according to their response to treatment, but care must be taken not to generalise too freely from the data given.

(a) *Species responding to cropping and fallowing in the same general direction.*

Euphorbia exigua (A) and *Polygonum aviculare* (B) were heavily and equally reduced by fallowing and cropping. Both species have a very limited period of germination, practically confined to the early months of the year. The spring cultivations were evidently favourably timed, and cut down these seedlings before flowering occurred, and there was no later germination from the remaining buried seeds. Restocking of the soil did not occur in either year and drastic reduction was the result.

Scandix pecten (C) was similarly affected, although its time of germination is in the autumn or very early in the year under field conditions. Its susceptibility to reduction under crop conditions is probably due to its late seed ripening, together with the lack of germination during the late spring and summer months. In 1926 the reduction appeared to be rather greater under crop than under fallow, but this difference might easily be due to experimental error, which is inevitably very large in an investigation of this nature.

Veronica hederifolia (D) resembled *Scandix* in its response, but was less adversely affected. The autumn and winter germination, coupled with the rapid flowering of the species, doubtless provided opportunity for early seed production with both forms of treatment, though the cultivations were sufficiently effective to prevent the main seeding and to cause a considerable steady reduction on balance.

With *Aethusa cynapium* (E), *Atriplex patula* (F) and *Polygonum convolvulus* (G) maximum germination occurs in the early months, but the period

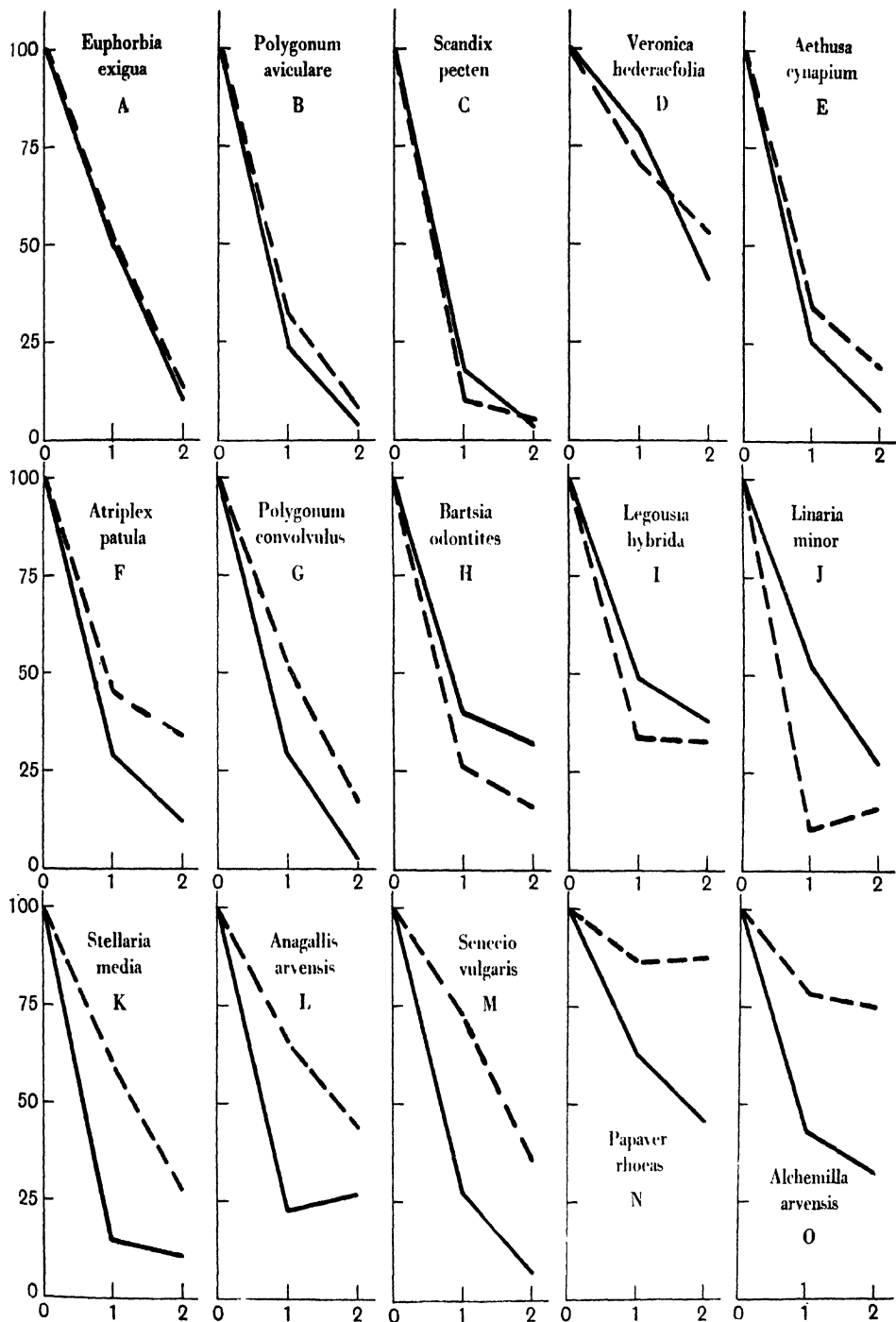


FIG. 1. Comparative effects of fallowing and cropping on the numbers of viable weed seeds in Rothamsted soil.

— = Fallowed.

--- = Cropped.

0 = 1925, before experiment started. 1 = 1926, after 1 year's treatment. 2 = 1927, after 2 years' treatment.

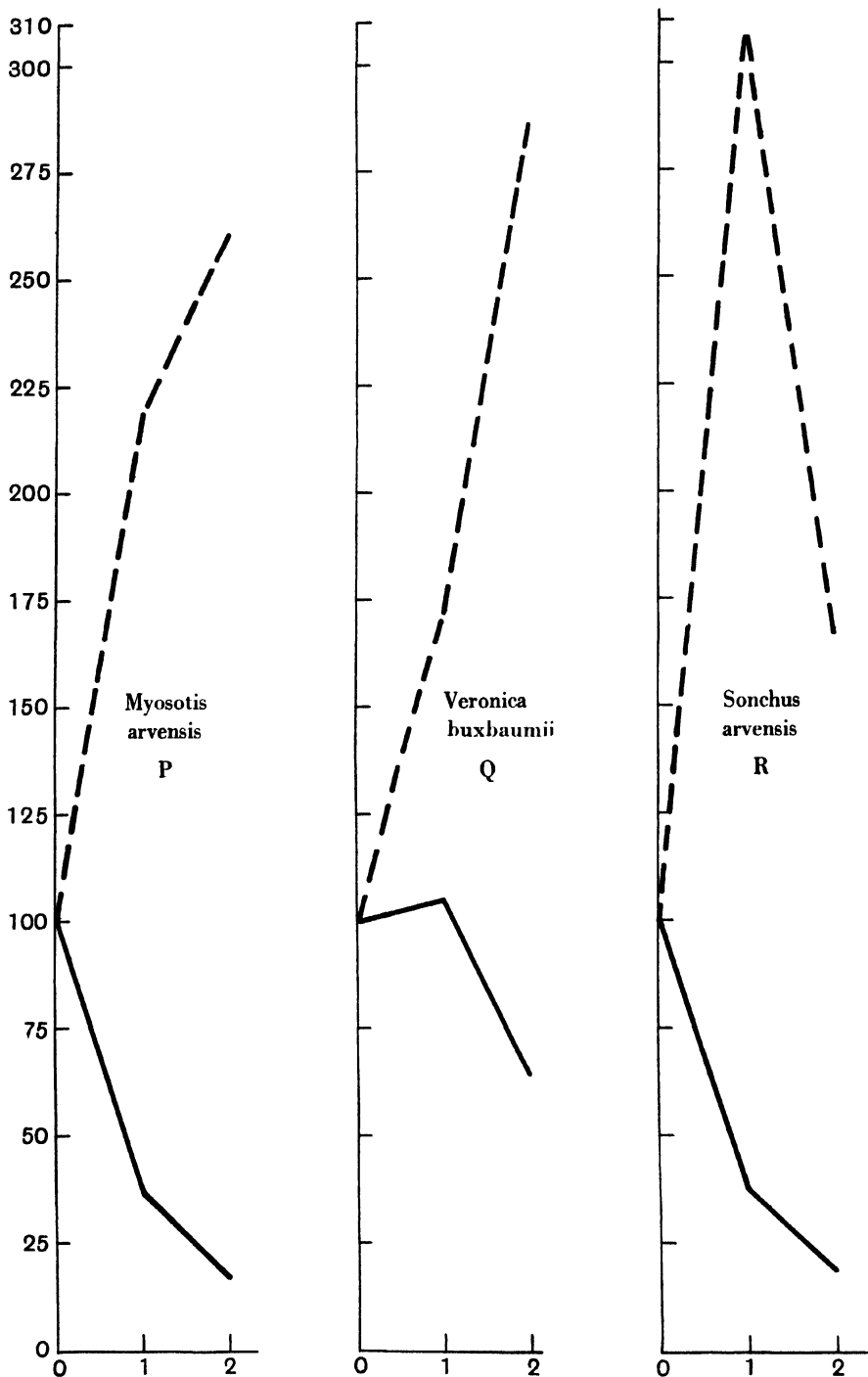


FIG. 2. Comparative effects of fallowing and cropping on the numbers of viable weed seeds in Rothamsted soil. — = Fallowed. --- = Cropped. 0 = 1925, before experiment started. 1 = 1926, after 1 year's treatment. 2 = 1927, after 2 years' treatment.

is more spread over and seedlings appear to a later date. As a result, the reduction under crop was rather less than under fallow, as a certain number of the later seedlings escaped being cut down and replenished the soil population to some extent.

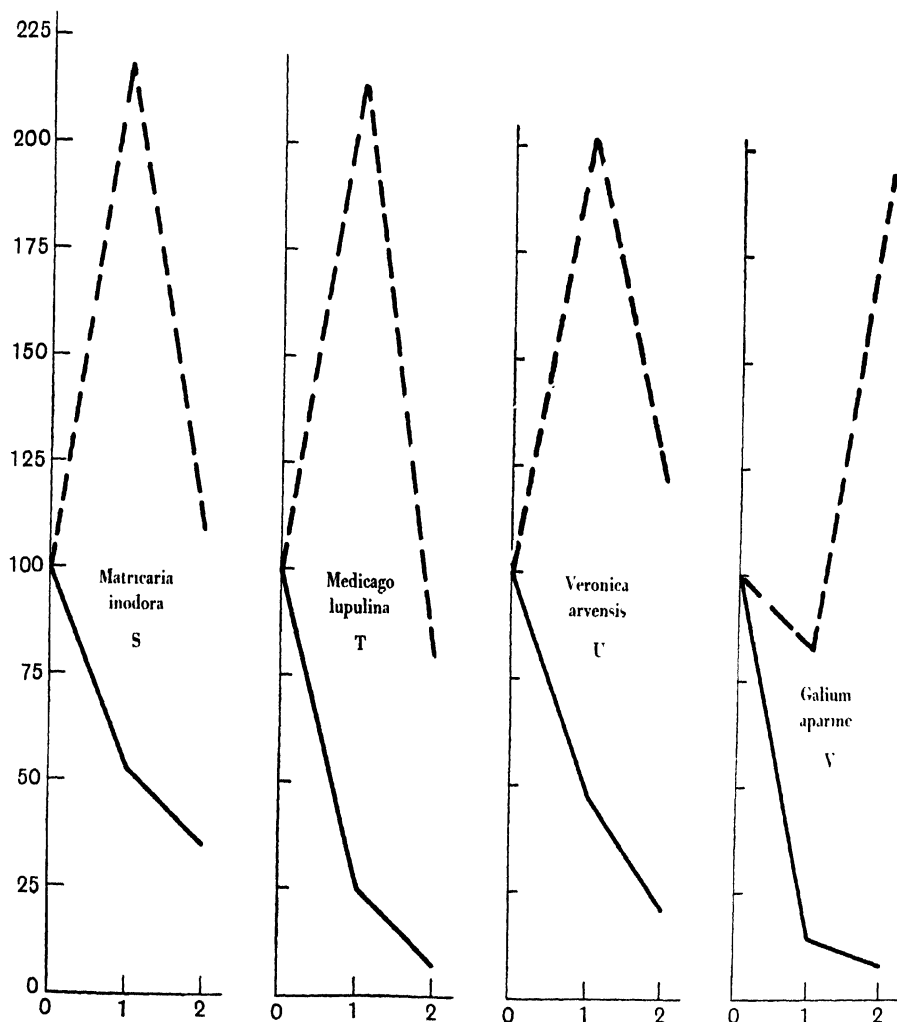


FIG. 3. Comparative effects of fallowing and cropping on the numbers of viable weed seeds in Rothamsted soil. — = Fallowed. --- = Cropped. 0—1925, before experiment started. 1 = 1926, after 1 year's treatment. 2 = 1927, after 2 years' treatment.

An unexpected reversal of the usual behaviour was obtained with *Bartsia odontites* (H), *Legousia hybrida* (I) and *Linaria minor* (J), in all of which the reduction under crop was greater than under fallow, particularly with *Linaria* in 1926. In all three cases the chief reduction under crop occurred in 1926, the

behaviour in 1927 varying with each species. It is difficult to account for this result unless it is in some way bound up with the different soil conditions induced by fallowing and crop cultivation. The three species are noticeably irregular in their occurrence in the field, and *Linaria* is very localised. As a general rule they are more or less insignificant members of the weed flora, but occasionally one or other forces itself into notice on account of its abundance in a particular year. *Linaria*, too, is very susceptible to crop competition, and the number of seeds that have germinated in these experiments gave promise of a much heavier infestation than actually occurred, owing to the young plants being crowded out by the crop. It must be remembered that the number of buried

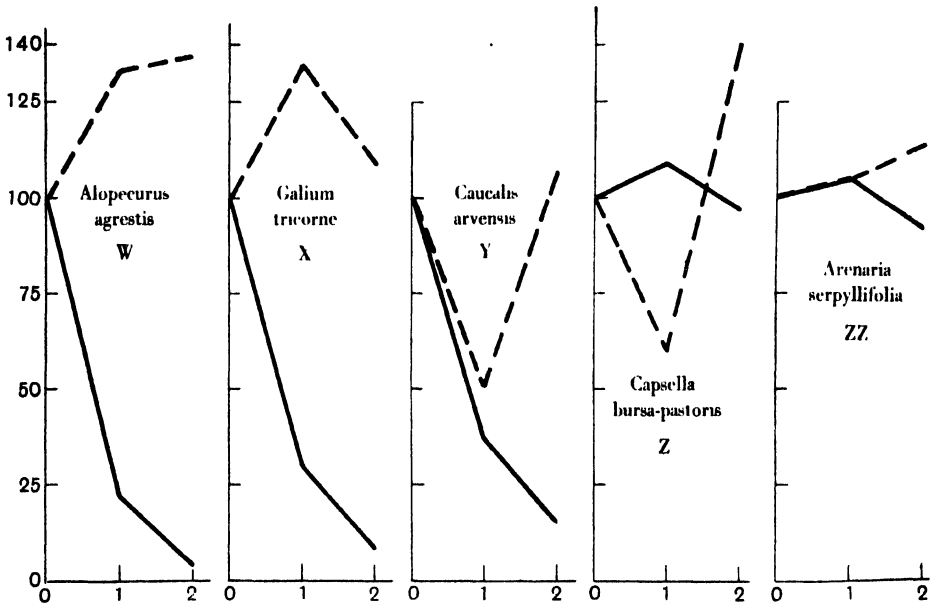


FIG. 4. Comparative effects of fallowing and cropping on the numbers of viable weed seeds in Rothamsted soil. — = Fallowing. --- = Cropped. 0 = 1925, before experiment started. 1 = 1926, after 1 year's treatment. 2 = 1927, after 2 years' treatment.

seeds per unit area at the time soil samples are taken is the result of the effectiveness or otherwise of the previous season's crop or fallow, and has been influenced by the climatic conditions during that season.

Stellaria media (K), *Anagallis arvensis* (L) and *Senecio vulgaris* (M) form another group in which reduction of soil population occurred with both treatments, fallowing being the more effective in the first year, and crop cultivation more advantageous in the second. The three species begin to bloom early in development and have a long continued flowering period, which enables young plants to aid seed replenishment even though they may be cut down before they have completed their growth. The behaviour of *Stellaria* and *Anagallis* in 1927 suggests that while the crop cultivation and competition continued to reduce

the buried seeds, there must have been periods during the fallowing when some seedlings were able to flower and fruit, thus keeping the soil population at much the same level at the end of the second season.

With *Papaver rhæas* (N) fallowing only reduced the buried seeds by about half, on account of their long period of dormancy, but crop cultivation had very little real effect, as a small reduction in 1926 was not continued the following year. This species is of different habit from any previously considered, in that it has a long period of growth before flowering occurs, and any plants which escape being cut down form such large numbers of seeds that relatively few are needed to replace the seeds which have been eliminated. This, coupled with the large proportion of seeds which escape by lying dormant, enables *Papaver* to maintain its position and to increase rapidly in favourable situations, rendering it a very pernicious weed on account of the difficulty in effecting a reduction. Fallowing is not an economic proposition, as recolonisation is very rapid from the dormant seeds, and so far no really effective method of eradication has been found. Fortunately, poppies are on the whole somewhat particular as to habitat, and it is only under unusual conditions, such as occur on Broadbalk with continuous wheat, that the weed will establish itself and spread freely on the less congenial soils. Doubtless, if this had been recognised twenty years ago, and the poppies carefully hand weeded from Broadbalk on their first appearance, the present state of affairs would never have arisen.

Alchemilla arvensis (O) closely followed *Papaver* in its behaviour, though the reduction was rather greater. Here again, the long period of dormancy kept an ample supply of seed in the soil, which gradually became capable of germination and provided means for re-stocking the soil later.

(b) *Species responding irregularly to cropping and fallowing.*

Most of the remaining species show much wider fluctuations than those so far considered, the effect of the two treatments being usually very different. With *Alopecurus agrestis* (W), *Myosotis arvensis* (P) and *Veronica burbaumii* (Q) a steady increase in numbers occurred under crop in both seasons, while fallowing heavily reduced the first two and caused an ultimate reduction in the third. All have short dormant periods, and will germinate freely on coming into favourable positions, and if they are not cut they seed freely, whereas if they are killed out before seeding there are relatively few dormant seeds left to germinate later and make good the loss. Evidently the hoeing of the wheat did not catch these three species at a vulnerable time, and their seed population profited thereby. Although *Alopecurus* and *Myosotis* can be so effectively reduced by fallowing, no relaxation of effort is admissible, as the free and abundant seeding from the remaining small percentage in the soil very soon recolonises the cleared area unless stringent measures are taken directly the land is again cropped.

Sonchus arvensis (R), *Matricaria inodora* (S), *Medicago lupulina* (T) and *Veronica arvensis* (U) showed fluctuations in soil population under crop, though

all were heavily reduced by fallow. The period during which germination may occur is relatively longer, and in some conditions, as probably occurred in 1926, fresh seedlings must come up after the spring cultivations, and, given a favourable season, abundant seed formation takes place. In other cases, as in 1927, either little fresh germination occurred after cultivation or else the season was unfavourable or the crop competition so severe that the loss of buried seeds was greater than the replenishment. The same factor of prolonged germination gave fallowing its opportunity at successive cultivations, resulting in the heavy increase noticed. The result with *Matricaria* must be accepted with some reservation owing to the small number of seeds found in the areas sampled, though the bulking of the results from 140 samples, each consisting of three borings, tends to minimise the experimental error due to the irregular distribution of seeds over the area. The same applies to *Galium tricornue* (X), of which the numbers were really too small to give reliable information.

Galium aparine (V), on the other hand, was present in quantity, and in common with *Caucalis arvensis* (Y) was first reduced under crop and then showed a heavy increase the next season, whereas fallowing reduced both species effectively. *Caucalis* has a long period of dormancy and from field observations appears to be very dependent on season. *Galium aparine* has a medium period of dormancy, and no obvious explanation of the discrepancy in behaviour in succeeding years presents itself other than the interaction of season, time of cultivation and crop competition.

Capsella bursa-pastoris (Z) and *Arenaria serpyllifolia* (ZZ) resemble one another in their resistance to fallowing, discussed earlier (p. 115), but their response to crop cultivation was quite different. *Arenaria* showed a hardly significant increase in each year, the re-seeding being slightly higher than the reduction. Although *Capsella* more than held its own under the first year's fallow it was considerably reduced by crop cultivation in the first year, and was able to increase in the second season. It is hard to find a feasible explanation of this, unless the conditions under crop were such as to encourage an extra amount of germination after the cultivations had occurred, crop competition being then so heavy as to kill out the seedlings at a very early stage, preventing soil replenishment. It is quite possible that at the time of hoeing weather conditions were such that the crop gave protection and kept the soil in good condition as a seed bed, whereas on the fallowed area drying out may have occurred and more seeds remained dormant in the soil.

IV. SUMMARY.

1. The weed seed population of the soil is greatly influenced by the type of crop grown. Soil conditions being similar, the composition of the flora under continuous wheat and barley is very much the same, but the relative abundance of the constituent species varies greatly, some being favoured by the wheat crop and others by the barley. On the whole, the spring cultivation

before barley sowing tends to keep the number of buried weed seeds below those occurring in the autumn ploughed wheat soil.

2. When fallowing operations are carried out the various species in the soil population are differently affected. Most species are reduced in number, but the degree of reduction ranges over a wide percentage, while a few species may even be increased. These variations seem to depend upon the correlation between the times of the fallowing operations and the periods of maximum germination of the different species, coupled with the length of their natural dormancy.

3. If the interval between processes of cultivations are too prolonged some species are able to reach maturity and replenish the soil with so many seeds that the beneficial effect of the fallowing is entirely lost. Weed species vary considerably in their ability to recolonise the soil in this way.

4. When land is cropped the processes of cultivation affect the weed flora more variably than is the case with fallowing. On the same area some species may be drastically reduced while others may be doubled or trebled in quantity. This again depends on the correlation between the date of sowing the crop, the method of cultivation, and the habits of the weed species as regards maximum period of germination and length of natural dormancy.

5. Some weed species respond to cropping and fallowing in the same general direction, being reduced by both methods of cultivation. Other species may be generally reduced by fallowing, but behave variably under crop, being increased or decreased in different seasons.

6. From the agricultural point of view it is apparent that unless fallowing operations can be carried out with a much greater degree of thoroughness than is usual, reduction of many weeds can be effected almost as well and more economically by intensified cultivation while the land is under crop. Other species, however, which tend to increase in some seasons under crop conditions, may be more effectively dealt with by fallowing if their predominance justifies the expense, which implies loss of crop as well as the cost of numerous cultivations.

The Influence of Length of Day on the Response of Plants to Boron.

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With Plates XVIII and XIX and one Figure in the Text.

CONTENTS.

	PAGE
I. INTRODUCTION	430
II. METHODS	431
A. Light Control	431
B. Temperature Conditions	432
C. Nutritive Conditions	432
III. EXPERIMENTAL DATA	434
A. <i>Vicia Faba</i>	434
1. Development under short day conditions	434
2. Dry weight and nitrogen content	436
(a) Influence of the length of day on the effect of boron deficiency	436
(b) Influence of boron deficiency on the effect produced by a shortened day	436
B. <i>Phaseolus multiflorus</i>	438
1. Development under short day conditions	438
2. Dry weight and nitrogen content	439
(a) Influence of the length of day on the effect of boron deficiency	439
(b) Influence of boron deficiency on the effect produced by a shortened day	439
C. <i>Hordeum vulgare</i>	441
1. Development under short day conditions	441
2. Tiller formation in the presence and absence of boron under full and short day conditions	443
3. Dry weight and nitrogen content	444
(a) Influence of the length of day on the effect of boron deficiency	444
(b) Influence of boron deficiency on the effect produced by a shortened day	446
4. Response to boron	447
D. <i>Glycine hispida</i>	449
1. Development under short day conditions	449
(a) Variety Biloxi	449
(b) Variety Mandarin	450

	PAGE
2. Dry weight and nitrogen content	450
(a) Influence of the length of day on the effect of boron deficiency	450
(b) Influence of boron deficiency on the effect produced by a shortened day	452
E. <i>Pisum sativum</i>	452
1. Development under short day conditions	452
2. Dry weight and nitrogen content	453
(a) Influence of the length of day on the effect of boron deficiency	453
(b) Influence of boron deficiency on the effect produced by a shortened day	453
IV. GENERAL DISCUSSION	454
V. SUMMARY	455

I. INTRODUCTION.

EARLIER work in this laboratory on the essential nature of boron in plant nutrition (2, 18), which has since been corroborated and extended by a number of other workers, has shown that although the whole plant eventually dies if deprived of this element, it is the meristematic tissues which are primarily affected by its absence. The symptoms of a deficiency of boron appear first at the growing apices of shoot and root, flowers are rarely if ever produced and, in the case of leguminous plants, nodules fail to develop normally (1). Beyond this, it has not yet been possible to assign any definite function to the element, in spite of a fairly thorough investigation of the matter.

Certain points, however, arose in the course of this earlier work which appeared of sufficient interest to merit further investigation, one of which is the subject of the present paper.

It had been noticed constantly that when plants were grown without boron in the spring or autumn a longer time elapsed¹ before the deficiency symptoms appeared, than if they were grown during the summer. Two obvious reasons for this at once suggested themselves, viz. the lower temperatures and the poorer light conditions in the spring and autumn compared with the summer. The problem, however, was not so simple as it looked at first, for this delay in the appearance of deficiency symptoms in the plants grown without boron was accompanied by a delay in the appearance of the flowers on the plants supplied with it. Further inquiry was therefore needed to see if this indicated either one, a special relationship between the function of boron and flower formation (although this element was already known to play a part in vegetative growth as well), and/or two, that the need of the plant for boron was affected by changes in external conditions such as light or temperature.

Several authors have shown that flowering may be controlled by the

¹ The reason why any time elapses before differences appear between the plants grown with and without boron is no doubt due to the presence of the small quantity of boron in most seeds which proves sufficient for the needs of the plant during the early stages of growth.

temperature to which the plants are exposed either during the night only (5), or during both day and night (9), or even during the process of germination only (13). Others again, of whom perhaps Garner and Allard's names are best known, have demonstrated that the flowering of most plants depends largely on the number of hours of daylight to which they are exposed. Certain plants, usually termed 'short day' plants, only produce flowers if the number of consecutive light hours are few enough, whereas others known as 'long day' plants, only form reproductive organs if exposed to a sufficiently long period of light. A 12-hour day is taken as the dividing line between these two categories, and photoperiodism is the term applied to the response of the plant to length of day conditions.

That nutritive conditions may control the response of the plant to changes in the length of day has been shown by Maximov (12) who found that although barley grown in water culture with full nutrients under a short day failed to form reproductive organs, if nitrogen were omitted from the solution, ears were produced. There seems no reason, therefore, why the reverse effect should not also hold and the nutritive requirements of the plant be modified under altered light conditions. It will be evident that these phenomena afford a ready means of testing out such problems as are referred to above, for by comparing the behaviour of plants grown with and without a supply of boron under a length of day which prevents or at any rate retards and limits flowering, but allows a good vegetative growth, with those grown under ordinary daylight, an answer may be obtained simultaneously to both the questions already brought forward. The temperature conditions for the two sets of plants must of course be similar. Water-culture experiments were accordingly carried out on these lines with a number of plants which were known to require boron under normal light conditions, and might be expected to respond to alterations in the length of day to which they were exposed.

II. METHODS.

The three main factors involved in investigations of this nature are light, temperature, and nutrition.

A. *Light control.*

The arrangements for exposing the plants to a definite number of hours of light were quite simple. A wooden shed, made as free from light as possible but provided with ventilation, was built on to a glasshouse of similar dimensions, wooden doors dividing the two compartments. Some of the benches were on wheels so that plants could readily be run from one compartment to the other as desired.

In each experiment one half of the plants received all the daylight available, which naturally varied slightly in the different experiments,

according to the season of the year, while the other was exposed to a 9- (and in a single instance to a 7-) hour day only. A 9-hour day was chosen since it seemed likely to be short enough to appreciably retard if not actually prevent flowering, and yet the light curtailment was not too drastic to prevent quite vigorous vegetative growth.

The hours selected for the 9-hour day were from 8 a.m. to 5 p.m. Greenwich Time, which during the months when summer time was in force (i.e. the greater part of the experimental season) became 9 a.m. to 6 p.m. The light treatment was carried out from the time the seedlings were first put into the nutrient solution, i.e. approximately one week after the seed was sown.

B. *Temperature conditions.*

No special apparatus was used to maintain equal temperature conditions in the shed and glasshouse during the period 5 p.m.–8 a.m. when the plants were separated, as the agreement between the two compartments in this respect seemed sufficiently close. The difference in the average minimum temperature in the two cases was surprisingly small, only ranging from 0.2–1.5° F. in a series of nine experiments (Table I). The agreement between the average maximum temperatures of the two compartments during these periods was not quite so close. As a general rule when the short day plants were first shut up for the night the temperature of the glasshouse was higher than that of the shed, but as the former cooled much the more rapidly large differences were of short duration only: For example, in the case of the experiment with *Vicia Faba* (July 17th–October 11th, 1930) closer examination of the charts shows that two hours after the plants had been separated the average difference in temperature between the two compartments was only 2.2° F., whereas the average difference in maximum temperature was as high as 10° F. An almost similar figure is obtained for the second experiment with *Phaseolus multiflorus* 1930.

C. *Nutritive conditions.*

The Rothamsted nutrient solution ¹ pH 6.2 was used throughout the season 1930, but a slight alteration in the proportion of the two phosphates was made in the following year to bring the pH to 5.0 and 5.5 in the case of the barley and soy bean cultures respectively, as it was thought that a more acid solution was desirable. The peas were grown in Zinzadze solution ² during one experiment, and in Rothamsted solution at a pH of

¹ KNO₃ 1.0 grm.; KH₂PO₄ 0.3 grm.; K₂HPO₄ 0.27 grm.; NaCl 0.5 grm.; MgSO₄ . 7H₂O 0.5 grm.; CaSO₄ . 2H₂O 0.5 grm.; Fe₂Cl₆ 0.04 grm. per litre H₂O.

² NH₄NO₃ 0.334 grm.; KNO₃ 0.166 grm.; Ca₃(PO₄)₂ 0.70 grm.; KCl 0.614 grm.; MgSO₄ . 7H₂O 0.5 grm.; CaSO₄ . 2H₂O 0.5 grm.; Fe₂(SO₄)₃ . 9H₂O 0.25 grm. H₂O per litre.

4.6 when the test was repeated. Salts declared free from boron by spectroscopic examination¹ were used in all forms of Rothamsted solution, but were not available for the Zinzadze cultures. The results, however, were identical irrespective of the type of solution used.

TABLE I.

Average Temperatures (° F.) in Glasshouse and Shed during the Period 5 p.m.–8 a.m. (G.M.T.) when the Plants were in Separate Compartments.

<i>Vicia Faba</i> , 1930.						
	March 31– June 23.		May 7– July 16. ²		July 17– October 11. ³	
	Max.	Min.	Max.	Min.	Max.	Min.
Glasshouse	65.7	47.7	73.5	52.9	72.8	51.9
Shed	60.1	46.8	68.6	53.1	62.8	50.4
Difference	5.6	0.9	4.9	0.2	10.0	1.5
<i>Phaseolus multiflorus</i> , 1930. <i>Hordeum vulgare</i> , 1930.						
	May 20– July 16. ²		July 23– September 20. ²		March 26– September 1. ²	
	Max.	Min.	Max.	Min.	Max.	Min.
Glasshouse	75.1	53.4	74.7	53.4	70.5	50.4
Shed	70.5	54.0	64.7	51.9	63.0	49.4
Difference	4.6	0.6	10.0	1.5	7.5	1.0
<i>Hordeum vulgare</i> , 1931. <i>Glycine hispida</i> , 1931. <i>Pisum sativum</i> , 1932.						
	March 19– August 13.		May 13– August 14.		April 22– May 24.	
	Max.	Min.	Max.	Min.	Max.	Min.
Glasshouse	69.2	50.3	72.9	54.4	71.2	49.5
Shed	64.4	51.2	68.3	55.1	65.2	48.9
Difference	4.8	0.9	4.6	0.7	6.0	0.6

One half of the plants under each light treatment received one part per million boric acid (H_3BO_3) in addition to the nutrient solution.

The seeds, graded by weight for each experiment, were germinated in damp sawdust, and the plants supported by wax corks were grown singly in glass bottles of 600 c.c. capacity. Renewal of the respective nutrient solutions was made at regular intervals, weekly changes being made after the first few weeks. Five plants were taken as the unit in every case.

Direct comparison was, therefore, available between plants subjected to summer daylight and those exposed to a 9-hour day (i.e. one somewhat

¹ The spectroscopic examination was carried out by Dr. Judd Lewis.

² Values for June 2–8, and August 24 missing.

³ 5 p.m.–10 a.m. for this experiment.

shorter than that characteristic of spring or autumn) both sets being grown under approximately similar and definitely summer conditions of temperature. Since each light treatment was further carried out with and without the addition of boron to the nutrient solution, it was hoped to distinguish between the effect of changes in light, apart from that of temperature, on the response of the plant to boron and flower production.

III. EXPERIMENTAL DATA.

Plants belonging to the long day category such as *Hordeum vulgare* (barley), *Vicia Faba* (broad bean), *Phaseolus multiflorus* (scarlet runner bean) and the Mandarin variety of *Glycine hispida* (soy bean) were principally grown, but experiments were also carried out with the Biloxi variety of *Glycine hispida*, a short day plant, and *Pisum sativum* (garden pea) which is intermediate in type.

A. *VICIA FABAE* (BROAD BEAN). *Sutton's Prolific Longpod*.

Experiments were carried out in 1930, March 31st–June 23rd, May 7th–July 16th, and July 17th–October 11th, the average normal day lengths in the three cases being 15 hrs. 8 mins., 16 hrs. 10 mins., and 13 hrs. 42 mins. respectively. A 9-hour day (8 a.m.–5 p.m. G.M.T.) served as the controlled short day in the first two cases, but a 7-hour day (10 a.m.–5 p.m.) was employed in the last experiment in order to obtain a greater difference between the normal and controlled conditions. The results of the three experiments were entirely consistent, so they will be considered together.

1. *Development under short day conditions.*

(i) Exposure to a 9- or 7-hour day retarded, but did not prevent the appearance of characteristic boron deficiency symptoms in the plants grown in boron free solution, and also slowed down the rate of the subsequent degeneration (Pl. XVIII, figs. 1 and 2).

An exact quantitative estimate of this delay was not easily made, owing to the inevitable slight variation among the replicates and the difficulty of stating precisely when the deficiency symptoms first appeared, but on an average it was found to be 3 to 6 days. Although this sounds hardly significant, the injury once evident in the full day plants progressed very rapidly, so that after a 3- to 6-day interval when the symptoms only began to appear in the short day series, the distinction between the two sets of plants was really well marked. In no case did shortening the day produce signs of degeneration similar to those of boron deficiency in plants supplied with boron.

(ii) The 9- or 7-hour day inhibited the growth of the shoot in length, an effect which has already been described by Deats (4) and many other

workers. In the case of the broad bean, however, the difference between the heights of the long and short day plants was only temporary. At an early stage (after about 5 weeks), when the full day plants supplied with boron were growing vigorously, the short day series were only 58.6 per cent. of the height of the controls, but when flowering had begun in the latter, elongation slowed down and finally almost ceased, whereas the short day plants continued vegetative growth for a much longer period, and eventually the heights of the series levelled up (cf. Pl. XVIII, Fig. 1 taken during an experiment with Fig. 2 taken at the end of an experiment).

(iii) Shortening the day retarded and limited flowering and fruiting in the plants supplied with boron (Pl. XVIII, Fig. 2). Although a 9-hour day allowed of some flower formation it was considerably delayed (4 to 14 days in the three experiments) and *much* less prolific than in the plants with normal daylight. To get some numerical idea of this effect on the flowering, the clusters of flowers were counted in the two series (Table II), when the full day plants appeared to be at the height of bloom.

TABLE II.

<i>Vicia Faba.</i>	<i>Water Culture.</i>	<i>Full Nutrients + Boron.</i>
		Average No. of flower clusters per plant.
Full day (average 15 hours 8 minutes)	.	17.8
9-hour day	.	7.2

Excellent pods were produced by the plants exposed to full daylight in the mid-summer series, but no pods were formed on the corresponding short day plants up to the close of the experiment (Pl. XVIII, Fig. 2). This probably does not mean that no pods would have developed under a 9-hour day, but that their formation was merely delayed. It was, unfortunately, not possible to investigate this point further as the plants had to be harvested in order to give dry weight figures comparable with the already mature full day plants, and questions of space prevented the alternative course of duplicating this part of the experiment.

(iv) Shortening the day in some cases induced a temporary wilting condition of the plants grown with boron, although they were in other respects entirely healthy and vigorous. This phenomenon usually occurred in particularly hot weather, but recovery did not take place during the night, as is usual when the wilting is brought about by excessive transpiration in the presence of an inadequate water supply. No question of lack of water can arise in the case of plants grown in nutrient solution, and in fact plants which showed this tendency to wilt invariably failed to absorb even their normal quantity of solution. Aeration of the solutions was tried without any improvement being obtained. Garner, Bacon, and Allard (8) hold

that the duration of the daily illumination period profoundly affects the water relations of the plant, and give examples to show that maximum turgidity is favoured by a light period which is optimal for increase in size. Caldwell (3) has reported the occurrence of wilting in tomatoes grown under short length of day, the explanation of which appears to lie in the reduced carbohydrate content of the plant. In support of this the *Vicia Faba* plants in the short day series which showed the greatest tendency to become flaccid were those which produced least dry weight, and one case of wilting which even occurred under full light conditions also proved to be an abnormally low yielding plant. No instance of wilting was observed in any of the plants without boron, whether grown under full or short (9-hour) day. Apart from their small size and moribund state which would naturally be accompanied by a reduction in all vital processes, including transpiration, it is an interesting point that according to Johnson and Dore (10) plants deprived of boron show an accumulation of carbohydrate. If the wilting be due to a lack of this constituent, therefore, the plants without boron would be the less likely to exhibit the phenomenon.

2. *Dry weight and nitrogen content.*

The figures for the dry weight and nitrogen content of the plants are given in Table III, the main features of which are described below.

(a) *Influence of the length of day on the effect of boron deficiency.*

Under both full and short day conditions removal of the boron brought about reductions in the yield of both shoot and root, but the decrease was much less marked in the case of the 9-hour day plants. Since the reductions in root-growth were in nearly every case greater than those in the shoot, plants grown in the absence of boron usually showed an increased shoot/root ratio.

Under both full and short day conditions, lack of boron caused a rise in the percentage of nitrogen present in the shoot. The actual nitrogen present, however, was in every case decreased, as would be expected from the very marked difference in size and vigour of the two sets of plants.

(b) *Influence of boron deficiency on the effect produced by a shortened day.*

Shoot growth was considerably reduced by a shortened day if boron was present, but it was slightly increased where boron was not supplied. This increase was probably due partly to the somewhat greater growth that occurred before the onset of the dying under short day conditions, and possibly also to a slight loss of dry weight undergone by the full day plants in their more advanced stage of degeneration. The development of roots, on the other hand, was hardly affected or slightly reduced by shortening the day if boron was present. An increase, however, was obtained in

TABLE III.
Photoperiodism of Vicia Faba, Water Culture, 1930.

Dry weights. Average of 5 plants.

Treatment.	March 31-June 23.				May 7-July 16.				July 17-October 11.			
	Shoot. gm.	Root. gm.	Total. gm.	Shoot. % N. in dry matter.	Shoot. gm.	Root. gm.	Total. gm.	Shoot. % N. in dry matter.	Shoot. gm.	Root. gm.	Total. gm.	Shoot. % N. in dry matter.
Full day + B	24.15	5.47	29.62	4.42	1.75	0.42			18.57	4.30	22.87	4.32
No B	4.53	0.63	5.16	7.19	2.62	0.12			3.64	0.55	4.19	6.62
Short day + B	11.61	4.21	15.82	2.76	2.89	0.34			9.85	2.89	12.74	3.41
No B	5.10	0.93	6.03	5.48	3.18	0.16			4.29	0.83	5.12	5.17
	Full day. Average 15 hours 8 minutes				Full day. Average 16 hours 10 minutes				Full day. Average 13 hours 42 minutes			
	Short day. Average 9 hours				Short day. Average 9 hours				Short day. Average 7 hours			

plants not supplied with boron. The shoot/ratio was in consequence decreased by shortening the day, both where boron was supplied and where it was withheld, in the former instance due to a decrease in the shoot and in the latter owing to greater root development.

A rise in the percentage of nitrogen in the shoot occurred on shortening the day whether boron was supplied or not, but so long as boron was present the actual nitrogen was lower in the short day than in the full day plants. On the other hand, where boron was omitted, more actual nitrogen occurred in plants grown under the short day conditions than under normal daylight, a result in keeping with the slightly heavier dry weight produced by the former.

As regards dry weight, therefore, a lack of boron very materially lessened or even negatived the effect of shortening the day to 9 or 7 hours, while a reduction in the length of day reduced the difference between the plants grown with and without boron.

B. *PHASEOLUS MULTIFLORUS* (SCARLET RUNNER BEAN (*Sutton's*
Prizewinner).

Two experiments were carried out with *Phaseolus multiflorus* in 1930 during May 20th–July 16th and July 23rd–September 20th respectively, the average normal length of day being 16 hrs. 21 mins., and 14 hrs. 11 mins. in the two cases. A 9-hour day was taken as the short day throughout. The main results of the two experiments were quite consistent, and in general confirmed those obtained with *Vicia faba*.

1. *Development under short day conditions.*

(i) Exposure to a 9-hour day retarded but did not prevent the appearance of boron deficiency symptoms (Pl. XVIII, Fig. 3). The delay amounted to from 3 to 6 days, but as in the case of *V. faba* no exact measure was possible.

(ii) A 9-hour day had a marked inhibitory action on growth of the stem in length, and although a few of the set receiving boron made a start to elongate, every plant, whether supplied with boron or not, failed to 'run' in the normal manner. Since stunting of stem growth is also a characteristic feature of runner beans suffering from a deficiency of boron under normal light conditions, it was important to distinguish between the apparently similar effect of the two factors. This was in general possible, as plants failing to 'run' owing to a lack of boron died at the apex of the stem, whereas the apices of those stunted from reduced light conditions remained healthy. Some difficulty, however, arose from the fact that the plants without boron under a short day died so slowly that their apices were apt to retain a green and healthy appearance for an abnormally long time, although in other respects, such as failure to form flowers and general

habit, these plants showed the characteristic symptoms of boron deficiency. With *V. Faba* certain abnormalities appear in the internal structure of plants deprived of boron (19) and it seems not unlikely that similar irregularities might be expected to occur in *P. multiflorus*. Material of these doubtful cases has, therefore, been pickled in the hope that anatomical investigations may lend support to the conclusions drawn from the external appearance of the plants.

(iii) Shortening the day entirely prevented flowering, although the plants exposed to full daylight flowered freely. This applied to the plants receiving boron only, as flowering did not take place even in full daylight unless boron were supplied. These results are in agreement with those of Tincker (17) and Maximov (12) who obtained no flowering with *P. multiflorus* when exposed to a 10- or 9-hour day respectively from the earliest stages of growth. Garner and Allard (7), on the other hand, record the reverse effect, viz. flowering under short day conditions only.

2. Dry weight and nitrogen content.

The dry weight figures for these two experiments with *P. multiflorus* are given in Table IV. Too much weight, however, must not be put on dry weight figures alone, for in experiments of this nature the physiological behaviour of the plant is the fundamental point. The fact that one set of plants elongates or flowers normally whereas another set differently treated do not, is of real importance, but such a change in habit is not necessarily accompanied by an equally striking difference in dry weight.

(a) Influence of the length of day on the effect of boron deficiency.

Under full day conditions removal of the boron brought about a reduction in dry weight of both root and shoot, and since the root was the more affected, a slight rise in shoot/root ratio was obtained. Under a shortened day, little or no reduction occurred in the weight of shoot when boron was lacking, though the root was definitely reduced in the second experiment. As a result an increase in the shoot/root ratio occurred in the latter case only.

The percentage of nitrogen in the shoot was slightly increased when boron was withheld under both full and short day conditions. In the case of the full day plants this was associated with a fall in the actual nitrogen present, but under short day conditions the actual nitrogen content remained unchanged whether or not boron was supplied.

(b) Influence of boron deficiency on the effect produced by a shortened day.

Shoot yield was reduced by a shortened day if boron was present but was little affected in its absence. As regards root growth the results were

TABLE IV.
Photoperiodism of Phaseolus multiflorus. Water Culture, 1930.
 Dry weights. Average of 5 plants.

Treatment.	May 20-July 16.					July 23-September 20.				
	Shoot. gm.	Root. gm.	Total. gm.	Shoot. Root.	Shoot. Actual N. gm. in dry matter.	Shoot. gm.	Root. gm.	Total. gm.	Shoot. Root.	Shoot. Actual N. gm. in dry matter.
Full day { + B No B	5.35	0.98	6.33	5.46	1.84	4.83	1.01	5.84	4.79	2.23
	3.05	0.44	3.49	6.93	2.51	1.88	0.36	2.24	5.21	2.77
Short day { + B No B	2.60	0.44	3.04	5.91	2.80	2.29	1.19	3.48	1.93	2.46
	2.35	0.40	2.75	5.88	3.12	2.03	0.63	2.66	3.21	2.70
	Full day. Average 16 hours 21 minutes					Full day. Average 14 hours 11 minutes				
	Short day. Average 9 hours					Short day. Average 9 hours				

not altogether consistent, although the behaviour in each case found corroboration in one or other of the *V. faba* experiments. If boron were supplied a reduction in root weight occurred when the day was shortened in the first of the *Phaseolus* trials, a result which agrees with two of the three tests with *V. faba* (Table III), but this reduction was not confirmed when the experiment was repeated. In the latter case, however, an increase of root occurred on shortening the day in the absence of boron, as had been found in all the experiments with *V. faba*. The effect on the shoot/root ratio was in consequence various. No tendency to form tubers under short day conditions was observed as Garner and Allard (7) and Tincker (16) have described, but this is in all probability to be attributed to the fact that they grew their plants in soil, and the experiments now under consideration were carried out in water culture.

With regard to the nitrogen content, the percentage in the shoot was increased when the day was shortened whether or not boron were supplied in the first of the two experiments only, the value being unaffected by the length of day in the second trial. In both cases, however, a reduction in actual nitrogen occurred provided boron were present.

As in the case of *V. faba*, therefore, a reduction in the length of day very considerably lessened the difference in dry weight produced by plants grown with and without boron, although it did not affect the need of the plant for this element.

C. *HORDEUM VULGARE* (BARLEY).

1930 Plumage Archer	{	Pedigree strains from National
1931 Goldthorpe, Standwell, Spratt Archer		Institute Agricultural Botany, Cambridge.

The trials were carried out from March 26th to September 1st in the first, and from March 19th to August 13th in the second season, the average lengths of the normal day throughout the experiments in the two years being almost identical, viz. 15 hrs. 20 mins. As already stated, the nutrient solutions employed in the two seasons were not quite the same, as a slightly more acid (pH 5.0) modification of the Rothamsted (pH 6.2) solution was used in the second year.

1. *Development under short day conditions.*

(i) The rate of growth was definitely retarded under the shortened day, but a much longer time elapsed before the influence of the length of day appeared compared with *V. faba*. This was no doubt due partly to the much longer growth period in the cereal plant, and also to the earlier time of year at which the barley was set up, the differences between the full and 9-hour day, at least during the first weeks of growth, being still

comparatively slight. With *V. faba* the superiority of the full over the 9-hour day plants was noticeable after about 10 days, whereas with all the four varieties of barley grown, 38 to 40 days elapsed before even slight differences in size could be detected.

(ii) The most outstanding effect of the short day on barley supplied with boron was the great delay in, or even prevention of ear formation. The precise behaviour depended on the variety, but in general the earlier the variety the less marked was the adverse effect of the short day. Among the four barleys tested, Standwell was the only one which produced a fair number of ears under a 9-hour day, although their appearance was delayed as much as 42 days, and the average number was only 14.6 per plant compared with 22.0 per plant developed under full daylight (Pl. XVIII, Fig. 4). Goldthorpe and Spratt Archer both formed ears eventually, but their emergence was also much retarded (58 and 51 days in the two cases) and their numbers reduced to an average of 3.4 and 12.0 per plant respectively, compared with 22.0 and 30.0 per plant under full day conditions (Pl. XVIII, Figs. 5 and 6). Plumage Archer, on the other hand, entirely failed to produce any ears at all (Pl. XVIII, Fig. 7).

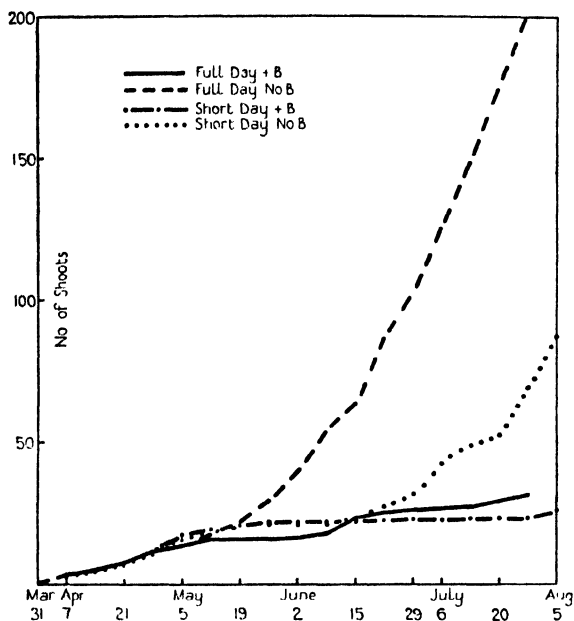
None of the short day plants were kept on to ripen, as the dry weight figures were wanted for comparison with the full day plants. It seemed improbable, however, that normal ripening off would have ever occurred. Very little grain showed signs of developing properly, and only in the case of Standwell was it possible to separate out any grain which might legitimately be termed fertile. Even then the yield was only 1.33 grm. per plant on an average of 5 plants, compared with 12.2 grm. under full daylight.

(iii) The shortened day also tended to bring about changes in habit, the effect being more marked in some varieties than others. Standwell and Goldthorpe, for example, assumed a spreading habit of a type which did not occur even in the early growth stages of the plants with full daylight. Plumage Archer, on the other hand, adopted a leafy, drooping habit, while Spratt Archer showed little departure from the normal beyond the extension of the vegetative period.

These results in respect of response to reduced length of day are in complete accordance with those of other workers, Tincker, for example (17), whose plants were grown under good cultural conditions with no nutrient deficiency. The point of interest at the moment, therefore, lies in the behaviour of plants deprived of boron, when subjected to a short day.

(iv) Shortening the day greatly retarded the appearance of the boron deficiency symptoms. Whereas the plants without boron exposed to full daylight started to fall behind the controls after an interval of one to two months, the 9-hour day plants without boron required approximately five to seven weeks *more* before they showed any inferiority to their corre-

sponding control set supplied with boron. The deficiency symptoms exhibited by these short day plants were precisely similar to those grown under full day conditions viz. a lack of ear formation¹ and a tendency to



continue vigorous tiller development throughout their life, as Sommer (15) has found to occur with other monocotyledons, though no premature tillering occurred as Morris (14) has described for wheat. None of the additional tillers in the barley were of any value, however, as they turned yellow at the apex and death of the shoot followed. Since one of the effects of shortening the day was to retard or even prevent ear formation, this abnormal tiller development afforded the best criterion as to whether or not the 9-hour day plants were suffering from a lack of boron. Shortening the day alone did not induce greater tillering (Table V), though Forster and others (6) found it caused an increase in the case of wheat, so it seemed evident that the abnormal rise in the number of tillers was rightly to be attributed to the deficiency of boron in the nutrient solution, both in the case of the full day and the 9-hour day plants.

2. Tiller formation in the presence and absence of boron under full and short day conditions.

It must be emphasized that much tiller formation late in the life of the plant is an *abnormal* feature, and as is seen in the text-figure above, which

¹ One instance occurred (Spratt Archer) where a single ear formed, but only sterile flowers developed.

illustrates tiller development throughout the life of these variously treated plants in the case of the Standwell variety, the control plants (full day with boron) had formed all tillers which were to be of any value for ear bearing during the first six weeks of growth, i.e. by May 12th. The slight increase noticeable from June 15th onwards, was due to the production of quite small shoots which did not develop ears. The plants without boron, on the other hand, showed no sign of slacking off in tillering, and the number of shoots increased without cessation until the end of the experiment. None of their tillers, however, whether formed early or late in the life of the plant produced ears.

The date at which a general distinction in size and habit first appeared between the plants grown with and without boron under full daylight coincided exactly with that when tiller development in the latter plants began to show signs of abnormality. This held for all varieties, although the dates were by no means similar in each case. It seemed justifiable, therefore, to take the point when the tiller curves first departed from the normal as an indication of the onset of boron deficiency. This proved of particular use in the case of the plants grown under short day conditions, where ear formation (the usual final criterion as to whether or not a plant was suffering from lack of boron) was much delayed or even suppressed. Further, by comparison of the tiller curves of the short and full day plants grown without boron, a fairly accurate measure of the delay in the appearance of boron deficiency symptoms brought about by the shortened day could be obtained. In the case of Standwell this delay amounted to five weeks.

3 *Dry weight and nitrogen content.*

In Table V the means of the average figures from the three varieties of barley grown in 1931 (each figure, therefore, representing the mean of 15 plants) are set out, those for Plumage Archer in the 1930 experiment being excluded as seasonal conditions were not conducive to altogether satisfactory growth, and the data, though entirely corroborative on all important points, were slightly less complete than those for the succeeding year's trial.

(a) *Influence of the length of day on the effect of boron deficiency.*

The total dry weight was slightly reduced by a lack of boron irrespective of the length of day, but the different parts of the plant were not all similarly affected. Under both full and short day conditions removal of the boron reduced the yield of ears and fertile grain to zero (0.07 grm. in column 2 represents 1 abortive ear which developed on a single Spratt Archer plant), but the yield of straw was only slightly reduced, a small

TABLE V.
Photoperiodism of Hordeum vulgare.
Means of 3 Varieties; 5 Plants in each. Water Culture, 1931.

Treatment.	Per plant.			Dry weight.			Straws.		Grain.	
	Total no. Tillers.	No. Ears.	% Earing Tillers.	Grain. gm.	Straw ¹ . gm.	Root. gm.	% N.	Actual. N. gm. in dry matter.	% N.	Actual. N. gm.
Full day { + B No B	36.2	23.00	63.50	10.25	30.98	3.99	0.82	0.237	2.29	0.257
	174.5	0.07	0.03	0.00	33.16	6.72	1.17	0.385	—	—
Short day { + B No B	36.9	10.00	31.20	0.44	33.75	6.46	1.40	0.463	3.13	0.027
	75.2	0.00	0.00	0.00	31.34	5.63	1.64	0.516	—	—

Full day. Average 15 hours 11 minutes
Short day. Average 9 hours

¹ Including sterile flowers.

increase even occurring in the plants exposed to full daylight owing to the large number of tillers produced.

An increase in root weight occurred in the absence of boron when full daylight was supplied, which considering the accompanying rise in tiller production suggests an association between root and tiller formation as occurs normally in the early development of the plant.

No increase in root, however, was obtained in these plants if they were grown under a 9-hour day. A reason for this may be suggested. Roots yielding approximately 6 gm. dry weight were apt to fill the bottles completely, so that the size of the culture vessels may possibly have been exerting a limiting action on growth.

Both the percentage and actual nitrogen in the shoot (which in this case consisted of straw only) were slightly increased in the absence of boron whether the length of day were full or short.

The effect of a lack of boron, therefore, was less marked under a 9-hour day than under full day conditions, but only in the case of the yield of root, was any definite alteration in the result obtained, and some explanation has been offered for this exceptional occurrence.

(b) Influence of boron deficiency on the effect produced by a shortened day.

The effect of the shortened day on the total yield was similar both in the presence and absence of boron, but owing to the drastic effect of a lack of boron in prohibiting ear formation distribution of the dry weight was necessarily different in the two cases.

Both a lack of boron and a shortened day reduced the development of fertile grain to zero, and no modification of this effect was obtained when both factors were in operation together.

A slight increase in yield of straw occurred with a 9-hour day in the presence of boron, whereas a slight decrease resulted if boron were not supplied. This decrease is probably without much significance since comparison is being made with a full day plant with quite abnormal tiller development and in consequence, an exceptionally heavy yield of straw.

As regards the root, where boron was supplied shortening the day resulted in a definite increase in yield, as Lubimenko and Szeglova (11) found to be the usual case with long day plants. In the absence of boron, however, a slight decrease in root growth occurred. Again, it is possible that the size of the bottle was exerting a limiting influence on root development, but the fact that the smaller yield of root was accompanied by a smaller number of tillers suggests that the result was a true one.

The percentage of nitrogen in the straw and grain was increased by growth under a short day in the presence (and in the case of the straw also in the absence), of boron. With the straw this was accompanied by an increase, but with the grain a decrease, in actual nitrogen present.

Although the removal of boron and shortening the day have in some respects similar results upon barley, yet the effects of the two factors can in other ways be readily distinguished; for example, both inhibited ear and grain formation, but *only* if boron was absent did abnormal tillering occur. This probably indicates that where no ears appeared in the plants supplied with boron grown under a short day it was a case of extreme delay rather than prevention. Real prevention occurred, however, apparently as the result of the death of the apical meristems, in the plants without boron, irrespective of the light conditions. No anatomical investigations were actually made in order to prove the point, but it is hoped to be able to follow up the question later. Since, in the event of ear formation being suppressed tillering received a stimulus, analogy with the result which frequently follows mechanical injury to the main growing apex was suggested.

Both removal of boron and shortening the day also tended to increase root growth, but the effect of each factor was counteracted by the presence of the other, e.g. shortening the day only increased root development provided no lack of boron occurred, and similarly a plant deprived of boron, which with a full day increased its root growth, failed to do so if subjected to a short day.¹ Further, although the same effect on root growth was obtained with the two factors, yet it seems probable that the nature of the influence exerted was not the same in the two cases, since where the day was shortened the subsequent increase of root was not accompanied by an increase in tiller formation, but where a lack of boron was associated with new root growth, fresh shoots were simultaneously developed.

4. Response to boron.

Before proceeding to describe the results obtained with other plants, some brief reference to the response to boron obtained with barley (and, as will be seen later, also with peas), in these experiments may not be out of place. In preliminary investigations already published (18) it seemed that boron was not essential for these species, though it was suggested at the time that the distinction between plants for which this element was (i) necessary, and (ii) advantageous was probably artificial, and that the difference in response was of degree only. Fortunately we have now been able to show that this is the case (Pl. XIX, Fig. 11), thus bringing these plants into line with the majority of other species tested, and the results into conformity with those of other workers.

This change in behaviour of plants grown in the later experiments is difficult to account for except by supposing that some source of boron

¹ A further possible explanation of this root behaviour is given under the discussion of dry weights.

unconsciously introduced in the earlier experiments (possibly by the nutrient solution or the glass culture bottles) had been removed. No alteration in this or in any other kind of technique, however, had been made as would afford any explanation on those lines, and salts, spectroscopically examined¹ for the presence of boron, with entirely negative results, and bottles lined with paraffin wax had in the case of barley been used before the response to a need for boron was obtained. Further, solution allowed to stand undisturbed in one of these uncoated bottles for six weeks² showed no trace of boron on spectroscopic examination, so that unless the presence of roots were essential before any boron could be dissolved out, it seems unlikely that the glass was a source of boron.

The danger of the glass furnishing sufficient of this element, however, seems to be small, since Sommer (15) states that even pyrex glass (a borosilicate) did not furnish her plants with sufficient of this element to mask the results, and in the experiments under discussion the glass bottles were definitely not of this type.

Whatever the correct explanation, it is evident that boron is essential for the normal development of barley as Sommer has shown, but at the same time its requirements must be considerably lower than those of other plants such as *Vicia Faba* or *Phaseolus multiflorus*, since the latter showed a marked response to a need for boron where no such need was exhibited by barley although grown under identical conditions.

All of the four varieties of barley just described failed to produce any fertile grain in the absence of boron, but occasional plants of another strain,³ Archer Goldthorpe 4/5/1 \times Goldthorpe-Spratt 18/1, developed a few malformed ears containing a little viable grain. A measure of the enormous difference between the yield of fertile grain from the plants grown with and without boron, however, may be gauged from the fact that in one season, only 3 seeds were obtained from 10 plants receiving no boron, whereas a similar number of plants supplied with boron yielded over 5,000.

This behaviour made it possible to grow successive generations of barley in water culture, so that the influence of the boron or no-boron treatment of the parent on the progeny could be investigated.

Plants derived from parents which had received no boron in the nutrient solution for four generations, apparently suffered no handicap from this pre-treatment, for they responded to the addition of boric acid and produced as good a crop of fertile grain as plants derived from parents supplied with boron throughout the same number of generations (Pl. XIX, Fig. 12).

¹ By which means less than one part H_3BO_3 in 180 million parts nutrient solution could be detected.

² The longest period which any solution normally remains in a bottle unrenewed is four weeks.

³ This barley was obtained from the cereal station, Ballincurra, but the locality does not appear to account for its difference in behaviour from the other varieties, since Cambridge grown strains have also produced grain in nutrient solution containing no boron in earlier experiments.

At the same time plants grown without boron and derived from parents which had received it for four generations, showed no superiority over those descended from parents grown for a similar number of generations without boron, thus indicating that no accumulation of this element had taken place, even sufficient for the completion of a single life cycle.

D. *GLYCINE HISPIDA* (SOY BEAN). Biloxi
Mandarin } Seed from Washington.

The soy bean is a particularly good subject for experiments with length of day, as within the one genus both long and short day plants exist. The Biloxi variety was selected as an example of a short day plant, while Mandarin served as a long day type. The experiments were carried out from May 13th to August 14th, 1931, the average normal length of day during this period being 16 hours 1 minute, while the controlled short day was 9 hours throughout. Except for a modification of the culture solution to obtain a pH of 5.5 the methods employed were similar to those used in the case of the other plants already described.

1. *Development under short day conditions.*

(a) *Variety Biloxi.*

Since this variety normally flowers under a short day, the plants exposed to a 9-hour day formed the standard by which flowering behaviour was judged, whereas in the broad bean, scarlet runner, and barley the full day plants served as the controls.

(i) After a preliminary period of three weeks during which no differences were noticeable, the 9-hour day reduced the vegetative growth very markedly and the plants remained dwarfed throughout the course of the experiment. Those receiving the full day made excellent vegetative growth (Pl. XVIII, Fig. 8) provided boron was present.

(ii) Identical symptoms of boron deficiency appeared 3 weeks after the start of the experiment simultaneously under full and short day conditions (i.e. no retardation occurred as in the case of the broad bean), but their development was considerably delayed in plants receiving only a 9-hour day. The dwarfing effect of the shortened day was in this case readily distinguished from the stunting due to lack of boron, as in the former case only did the growing apices remain green and healthy.

(iii) Pods were developed freely from flowers of a cleistogamous nature (observed also by Garner and Allard (7)) under a 9-hour day, provided boron was supplied, but no flowering of any kind occurred in the plants exposed to full daylight up to the end of the experiment (August 14), the natural day being evidently still too long to allow of it.¹

¹ Similar plants carried on longer showed flower buds on October 31, when the length of day was 9 hrs. 41 mins., but they failed to open. The low temperature was probably responsible for this.

(b) *Variety Mandarin.*

Growth of the Mandarin variety was somewhat slower than that of the Biloxi series, and differences between the plants grown with and without boron did not appear until 2 weeks after they were evident in the latter. The results with Mandarin were in some respects less well defined than in the case of Biloxi, as the reduction in length of day to 9 hours exerted such a drastic effect that differences between the plants grown with and without boron were not easy to detect. The results obtained, however, were in no way contradictory, but rather lacked definition.

(i) After about 4 weeks from the start the short day plants fell behind those receiving full daylight and eventually the difference in size between the two sets became very marked (Pl. XIX, Fig. 9).

(ii) Exposure to a 9-hour day greatly retarded the appearance of the boron deficiency symptoms, and even to the end of the experiment they were not very definite. This was, no doubt, due to the overwhelming effect of the short day which prevented sufficient growth being made as should use up the original supply of boron present in the seed. From the appearance of the plants, however (Pl. XIX, Fig. 9), it is evident that they were distinctly poorer than those receiving boron, and although a few pods were actually formed on some of these plants, they showed a tendency to drop off without developing properly, so that it seems justifiable to conclude that the absence of the element was exerting some harmful effect, even if the deficiency symptoms were somewhat ill defined.

(iii) Flowering and pod formation was delayed and much reduced, but not altogether prevented, by growth under a 9-hour day. The extent of the delay could not be determined as flowering was of a cleistogamous nature under the short day, and although small petals were produced no opening of the buds was ever observed.

2. *Dry weight and nitrogen content.*

The figures for the dry weights and nitrogen content of the shoots of both Biloxi and Mandarin soy beans are given in Table VI.

(a) *Influence of the length of day on the effect of boron deficiency.*

In the case of both varieties the yields of shoot and root were definitely reduced by a lack of boron under full and short day conditions, though less markedly so in the case of the short day. The reduction in the yield of root was greater than that of the shoot under a full day, so that a rise in shoot/root ratio was obtained. This, however, did not occur under a 9-hour day, since the shoot and root were affected very similarly by a lack of boron.

The percentage of nitrogen in the shoot showed a marked rise in the

TABLE VI.
Photoperiodism of Glycine hispida. Water Culture, 1931.
Dry weights. Average of 5 plants.

Treatment.	Biloxi (short day type).					Mandarin (long day type).				
	Shoot. gram.	Root. gram.	Total. gram.	Shoot. Root.	Shoot. N. gram. in dry matter.	Shoot. gram.	Root. gram.	Total. gram.	Shoot. Root.	Shoot. N. gram. in dry matter.
Full day { + B ¹ { No B	16.28	7.33	23.61	2.22	1.48	18.20	7.94	26.14	2.29	1.58
	2.51	0.47	2.98	5.34	3.86	1.47	0.49	1.96	3.00	4.28
Short day { + B { No B	5.85	1.93	7.78	3.03	2.53	2.50	1.15	3.65	2.17	3.83
	1.89	0.57	2.46	3.32	4.23	1.53	0.89	2.43	1.72	4.27
Full day. Average 16 hours 1 minute. Short day. Average 9 hours										

¹ Average four plants only.

absence of boron irrespective of the length of day. The actual nitrogen, however, was considerably reduced in the shoots of all plants where boron was lacking.

(b) *Influence of boron deficiency on the effect produced by a shortened day.*

Shortening the day reduced the yield of shoot and root very considerably in both varieties, provided boron was present. In the absence of boron, on the other hand, the dry weight of shoot was only slightly if at all reduced by the 9-hour day, and the yield of root was increased, especially in the case of the long day variety Mandarin. The shoot/root ratio was in consequence slightly increased or unaffected by short day conditions if boron were supplied, but was definitely reduced in its absence.

A rise in percentage of nitrogen and fall in the actual nitrogen occurred in the shoot under a 9-hour day in both varieties where boron were supplied, but no significant change occurred if boron was not present.

E. *PISUM SATIVUM* (GARDEN PEA). *Sutton's Harbinger.*

Peas are an example of plants where the lowering is little affected by a fairly wide range of length of day, and they thus afford a convenient link between definitely long and short day plants. The pea experiments were carried out during April 27th–June 27th, 1931, and repeated during April 22nd–June 24th, 1932, the average normal lengths of day being 15 hours 53 minutes and 15 hours 28 minutes respectively, whereas the controlled short day was 9 hours throughout in each case.

1. *Development under short day conditions.*

(i) Although two to three weeks elapsed before any differences became noticeable, growth was retarded under a 9-hour day, the short day plants remaining smaller than the controls throughout the experiment (Pl. XIX, Fig. 10).

(ii) No prevention or even delay in flowering occurred, but the progress of maturation, as seen in pod formation and development, was definitely retarded.

(iii) As regards the time of appearance of boron deficiency symptoms¹ in the two sets of plants the results from the two experiments were not quite consistent. A slight, but quite definite delay (six days) occurred in the appearance of the deficiency symptoms in the short day plants in the first experiment, whereas no such retardation was found in the succeeding year. On account of the difficulty in detecting the first signs of a lack of boron in peas and the inevitable individual variation

¹ See section 4. Response to boron, under Barley.

among the plants, too much weight must not be attached to this discrepancy. The delay, when it did occur, was less marked than in the broad bean, though the time interval in the latter case was even smaller.

2. *Dry weight and nitrogen content.*

As the dry weight figures for the two experiments are very similar, those for the second trial only will be given (Table VII).

TABLE VII.
Photoperiodism in Pisum sativum. Water Culture. 1932.
Dry weights. Average of five plants.

Treatment.	Shoot.		Root. gram.	Total. gram.	Shoot. Root.	Shoot.	
	Stems and Leaves gram.	Pods. gram.				% N. in dry matter.	Actual N. gram.
Full day { + B ¹ . { No B	1.76	3.12	0.54	5.42	9.67	2.34	0.13
	1.16	0.00	0.20	1.36	6.13	2.97	0.04
Short day { + B ¹ . { No B	1.03	1.30	0.36	2.69	6.53	3.39	0.09
	1.17	0.00	0.25	1.42	5.10	3.37	0.05
Full day. Average 15 hours 28 minutes							
Short day. Average 9 hours							

(a) *Influence of the length of day on the effect of boron deficiency.*

Under both full and short day conditions a lack of boron reduced the yield of pods to zero, but the dry weight of the leaf and stem part of the shoot were little if at all affected. The weight of roots was also lowered where boron was not supplied, the reduction being specially marked under full day conditions, and since the yield of the shoot was reduced more than that of the root, a decrease in shoot/root ratio occurred in each case. The percentage of nitrogen in the shoot was hardly affected by a lack of boron irrespective of the length of day, but the actual nitrogen present was much reduced in both cases.

(b) *Influence of boron deficiency on the effect produced by a shortened day.*

In the presence of boron shortening the day brought about a small though definite reduction in the yield of all parts of the plant, more especially in the shoot, so that the shoot/root ratio was decreased. No reduction in yield, however, occurred where boron was not supplied.

¹ Average four plants only.

The percentage of nitrogen in the shoot was increased by a shortened day if boron were present, but only slightly raised in its absence. The actual nitrogen, on the other hand, was little, if at all, affected by a reduction in the length of day, whether or not boron was supplied in the nutrient solution.

A shortened day, therefore, has a much less striking effect upon the growth of the pea plant than the omission of boron from the nutrient solution.

IV. GENERAL DISCUSSION.

As stated in the introductory portion of this paper, the object of these experiments was to obtain a comparison between various plants grown under full (summer) and short (spring and autumn) lengths of day respectively, both sets, however, receiving similar and definitely summer conditions of temperature. Since one half of the plants were supplied with boron, whereas the remainder received none, it was possible to determine the relative importance of the two factors, light and temperature, in causing the retardation both in the appearance of the boron deficiency symptoms and in the production of flowers in spring or autumn grown plants, compared with those grown in the summer. At the same time it was hoped to obtain evidence as to whether or not any correlation existed between these two phenomena.

In the case of *Vicia Faba* (broad bean), *Phaseolus multiflorus* (scarlet runner bean), *Glycine hispida* variety Mandarin (soy bean) and *Hordeum* (barley), shortening the day to 9 hours definitely retarded the appearance and progress of the symptoms of a deficiency of boron, thus proving that the reduction in the length of day rather than the temperature was the controlling factor in this case. Only with the Biloxi variety of soy bean and *Pisum sativum* (garden pea) was no delay in the appearance of deficiency symptoms obtained, but as these were examples of plants which were not definitely long day in type, the difference in their behaviour under the altered light conditions is probably accounted for.

In order to determine whether or not the delay in flowering which accompanies the delay in the appearance of the boron deficiency symptoms indicates an association between the function of boron and the production of flowers, it is best to take the case of such plants as the scarlet runner or Biloxi soy bean, where the shortened day not only retarded but actually prevented flowering throughout the course of the experiment. It will be remembered that in these plants there was a sharp distinction between the growth, habit, and development of the plants grown with or without boron, although neither of them flowered. This indicates that apart from flowering, boron exercises an important influence on the growth of the plant, though there is still nothing to preclude its being of special importance for

flower formation. All the evidence so far obtained goes to show the importance of boron for meristematic activity. In its absence the stem and root apices are the first parts of the plant to be affected, and since flower initials are essentially meristematic in nature, there seems every reason to believe that boron is as necessary for their normal development as for that of vegetative apices. That shortening the day does not of itself injure the flower or vegetative meristems is shown by the fact that plants failing to flower or elongate when exposed to an unfavourable length of day, do so as soon as the light conditions become favourable. A plant deprived of boron, on the other hand, almost always fails to flower, vegetative apices die irrespective of the light conditions, and even if the deficiency of boron is remedied before death of the plant is complete, recovery invariably takes place by means of entirely fresh lateral growth and not by renewed growth of the affected parts. It would seem, therefore, that no *special* correlation exists between the function of boron and flower formation except in so far as this element is associated with the growth of all types of meristematic tissues, flower primordia included.

V. SUMMARY.

1. The reduced length of day rather than the lower temperature is the factor controlling the delay in appearance of boron deficiency symptoms during the spring and autumn, compared with the summer months.

2. No special association between the function of boron and flower production was found, except in so far as flower formation is meristematic in nature, and is in consequence affected by a lack of this element.

3. Within the range of 7-16 hours, the length of day has no bearing on the need of the plant for boron, since with one possible exception, where the case remained unproven (Mandarin soy bean), death of all the plants ensued where this element was not supplied irrespective of the length of day to which they were exposed.

4. The deficiency symptoms characteristic of a lack of boron were similar under both long and short day conditions, although they were less pronounced and their rate of progress retarded if the day were short.

5. In no case did shortening the day produce degeneration effects similar to those induced by a lack of boron. Although the influence of the two factors in certain instances appeared similar, as where flowering was completely prevented, the resemblance was superficial only.

6. The presence of each factor modified the influence of the other:

(a) In the absence of boron the influence of the length of day was less striking than where boron was present.

- (b) The boron deficiency symptoms were less pronounced under short day than under full day conditions.

7. The lack of boron exerted a more fundamental influence on the plants than a reduction in length of day to 9 or 7 hours.

In conclusion, thanks are due to Dr. W. E. Brenchley for her unfailing interest and helpful advice throughout this investigation.

Acknowledgements must also be made to the National Institute of Agricultural Botany, Cambridge, and the Cereal Station, Ballinacurra, for the supply of pure line barley, and to the Bureau of Plant Industry, Washington, for the pedigree soy bean seed, and to the Chemical Department and Mr. V. Stansfield, of the Rothamsted Experimental Station, for the nitrogen determinations and photographs respectively.

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EXPLANATION OF PLATES XVIII AND XIX.

Illustrating Miss Katherine Warington's paper on 'The Influence of Length of Day on the Response of Plants to Boron'.

PLATE XVIII.

Figs. 1-10. Plants grown in water culture showing development under full and nine hour length day, with and without the addition of 1 p.p.m. boric acid in the nutrient medium. 1. *Vicia Faba* (broad bean) mid-growth stage. 2. *V. Faba* final growth stage. 3. *Phaseolus multiflorus* (runner bean). 4. *Hordeum vulgare* (barley) variety Standwell. 5. *H. vulgare* variety Goldthorpe. 6 *H. vulgare* variety Spratt Archer. 7. *H. vulgare* variety Plumage Archer. 8. *Glycine hispida* (soy bean) variety Biloxi.

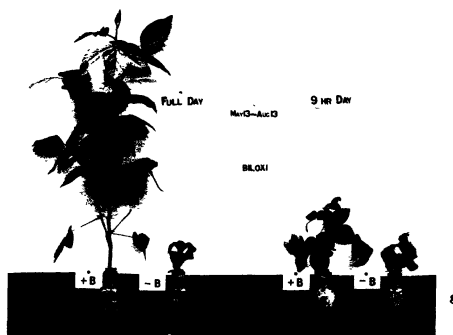
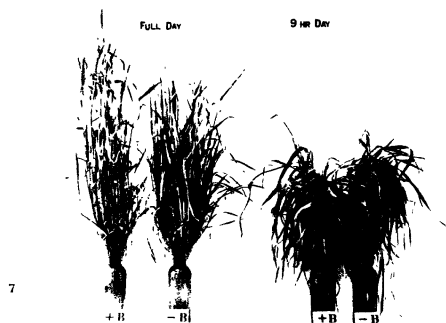
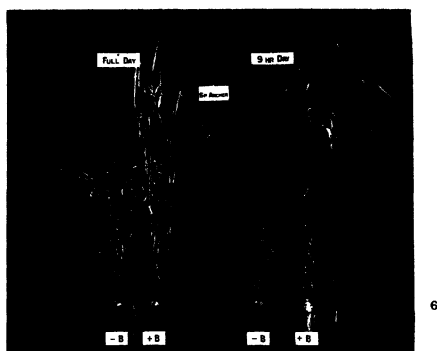
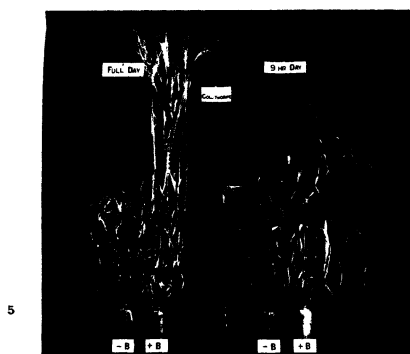
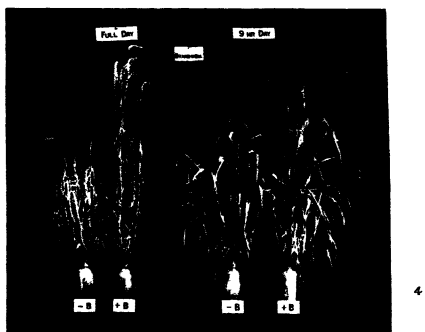
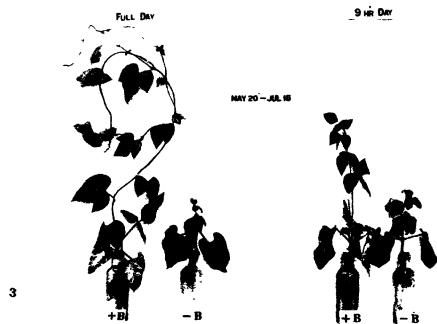
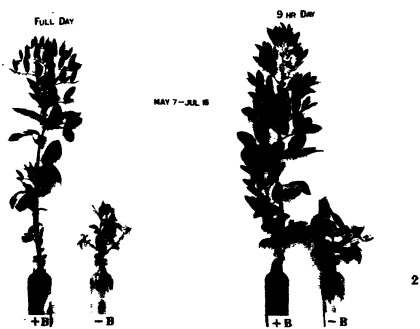
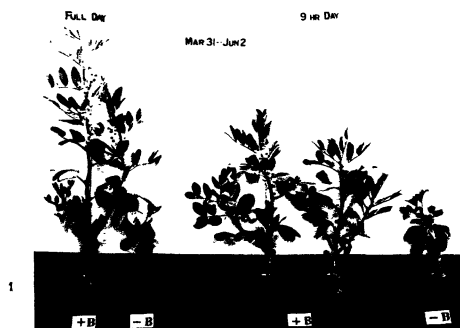
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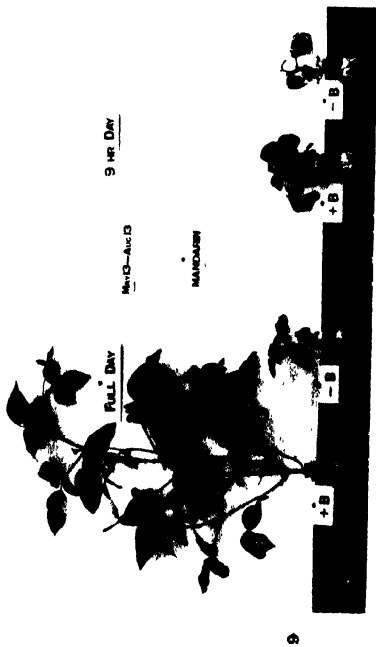
Fig. 9. *G. hispida* variety Mandarin.

Fig. 10. *Pisum sativum* (pea).

Fig. 11. Three different varieties of barley grown in water culture under normal light conditions with and without boron.

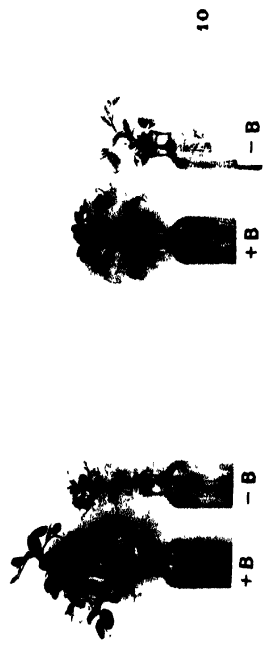
Fig. 12. Growth of the fifth generation of barley with and without 1 p.p.m. boric acid in the nutrient solution. Left to right: (1) 4 years no boron, 5th year with boron, (2) 4 years no boron, 5th year no boron, (3) 4 years with boron, 5th year no boron, (4) 4 years with boron, 5th year with boron.



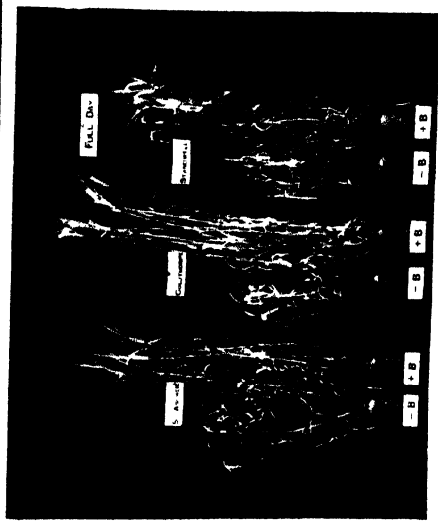


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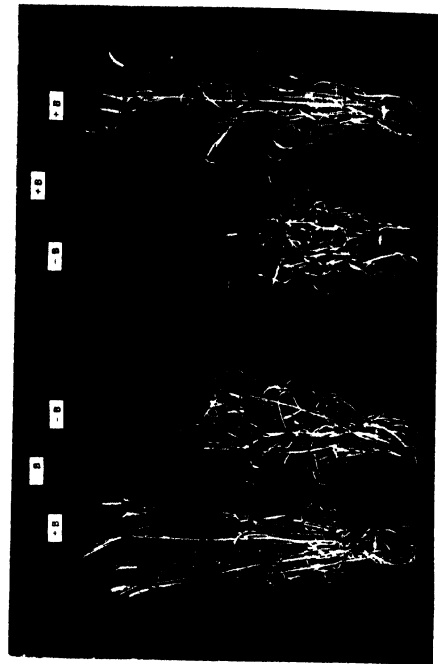
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WARINGTON — RESPONSE OF PLANTS TO BORON.

Hubb. London

A STATISTICAL EXAMINATION OF THE YIELD OF MANGOLDS FROM BARNFIELD AT ROTHAMSTED¹.

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(With Six Text-figures.)

INTRODUCTION.

THE records of the classical experiments of the Rothamsted Experimental Station form unique material for statistical investigations on crop-weather relationships. Dr R. A. Fisher examined statistically the yield of dressed grain from the Broadbalk wheat field⁽¹⁾ and in a subsequent paper⁽²⁾ studied the influence of rainfall on the yield of wheat. Miss Mackenzie examined the yield of dressed grain from the Hoos Field barley experiment⁽³⁾ and Dr Wishart and Miss Mackenzie⁽⁴⁾ investigated the influence of rainfall on the barley crop. In the present paper a similar analysis is made on the series of yields of mangolds from the different plots of Barnfield. The investigation covers a period of fifty-five years: 1876–1930, both years inclusive.

Root crops have been grown in Barnfield since 1843, excepting 1853–5 when barley was grown without manure. From 1876 onwards, mangolds were cultivated each year except in 1908 and 1927, when the crop was swedes. The scheme of manuring for the different plots is shown in Table I.

Strips 1, 4, 5, 6 and 8 of Series O, N, A, AC and C are selected for the present investigation. Even in these twenty-five selected plots several minor alterations have taken place from time to time, but in the main the treatment has remained uniform.

CHANGES IN THE MANURIAL TREATMENT.

(a) In general, one-third of the nitrogenous manures is sown with the seed and the remaining two-thirds are top-dressed, but in 1892 one-half was applied at the time of planting, and in 1896 and 1900 the whole of the nitrogenous manures was applied as top-dressing.

¹ Part of thesis approved for the degree of Ph.D. in the University of London, 1932.
Journ. Agric. Sci. xxiii

Table I. *Experiment on mangolds, Barnfield, beginning 1876.*
Quantities of manures per acre per annum.

Strip	Strip manures.				
	Farmyard manure tons	Super- phosphate cwt.	Sulphate of potash lb.	Sulphate of magnesia lb.	Salt lb.
1	14	—	—	—	—
2	14	3·5	500	—	—
4	—	3·5	500	200	200
5	—	3·5	—	—	—
6	—	3·5	500	—	—
8	—	—	—	—	—

Nitrogenous manures running across all the strips.

Series O.	None.
„ N.	Nitrate of soda, 550 lb.
„ A.	Ammonium sulphate, 412 lb.
„ AC.	Rape cake, 2000 lb., and ammonium sulphate, 412 lb.
„ C.	Rape cake, 2000 lb.

(b) The usual dressing of 550 lb. per acre of nitrate of soda was omitted in the years 1885, 1901 and 1903. Plot N, however, received the manure in 1903. In 1927 no top-dressing was given.

(c) Mixture of muriate and sulphate of ammonia, each 200 lb. per acre, was given up to 1916, while from 1917 onwards sulphate of ammonia alone was supplied at the rate of 412 lb. per acre. In the years 1885, 1901 and 1903 this source of nitrogen was omitted. There was no top-dressing in 1927.

(d) For the four years 1917–20, the usual dressing of 2000 lb. of rape cake was omitted.

(e) For the seven years, 1896–1902, a dressing of 400 lb. of basic slag was substituted for the usual dressing of superphosphate.

(f) The usual dressing of 500 lb. of sulphate of potash was omitted in the years 1917 and 1918, while in 1919 and 1920 it was replaced by the equivalent amount of muriate of potash.

(g) In the years 1917 and 1918 the usual dressing of 200 lb. of sulphate of magnesia was not applied.

Throughout the period under investigation, the crop has remained the same except in 1908 and 1927, when swedes were sown owing to the failure of the mangold crop. The Yellow Globe variety of mangolds has been used throughout the period. The usual spacing is 26 in. between the rows and 11 in. within the rows except in the years 1882 and 1887, when the rows were 26½ in. apart, and in 1898 the plants were thinned to 10 in. In 1930 the half of each plot had rows 26 in. apart, while the other half had rows 20 in. apart. The yields of rows spaced 26 in. apart are taken for the present study.

As observed above, swedes were grown in 1908 and 1927 instead of mangolds. The yield of swedes is, however, taken in this study. No years have been rejected, though in some the manures were omitted. The omission of the manures has for the particular seasons resulted in a lower yield but in some years as low, or even lower, yields were obtained, although the plots received their usual manurial dressings. It is indeed very difficult to ascertain the effect of the various changes upon the statistical results, but it is reasonable to suppose that the influence, if any, of such temporary alterations would appear as annual variation.

The object of the present paper is to study the variation in yield from year to year on the above-mentioned twenty-five plots, and to examine the relationship, if any, between manurial treatment, mean yield and the variability of the yields. The influence of rainfall on mangolds is studied in another paper.

METHOD OF ANALYSIS.

The method developed by Dr Fisher⁽¹⁾ is used in the following investigation. It involves fitting polynomials to the various series of plot yields and analysing the total variance into (a) the amount due to average rate of deterioration, (b) slow changes other than steady deterioration, and (c) annual causes. A polynomial of the fifth degree is fitted to the series of yields of mangolds. The smooth curves are drawn to show the actual course and extent of the slow changes in the mean yield occurring in the differently treated plots. For the arithmetical procedure recourse should be had to Fisher's paper entitled "The influence of rainfall on the yield of wheat at Rothamsted" (2), pp. 112-15). Precisely the same notation is used throughout this paper.

RESULT OF ANALYSIS.

The secular changes in the series examined are given in Table II. The measures x_2' to x_6' of the components of change of the first to the fifth degree are employed since these are directly comparable with the standard residue.

VARIABILITY AND ITS CAUSES.

As observed above, the variation in the yield is analysed into three parts: (a) deterioration, (b) slow changes, and (c) annual variation. The deterioration is, in this study, represented by a linear function, although

164 *Statistical Examination of the Yield of Mangolds*

theoretically it is probably more truly represented by an exponential curve.

Table II. *Secular changes in the series examined.*

	Strip 1	Strip 4	Strip 5	Strip 6	Strip 8
Series O.					
x_2'	- 1.8441	- 4.8686	- 4.1045	- 2.5779	- 3.0525
x_3'	- 15.7093	+ 0.4512	- 0.5544	+ 0.7390	- 0.4844
x_4'	- 3.6253	- 0.4860	+ 0.5138	+ 1.0032	+ 1.6053
x_5'	+ 2.2440	+ 2.1362	+ 2.2500	+ 1.9927	+ 1.7843
x_6'	- 8.2920	- 3.1871	- 3.3227	- 2.7522	- 1.9913
Standard residue	5.3685	1.7785	1.9175	1.5600	1.5505
Series N.					
x_2'	+ 9.4398	- 0.5723	- 3.2468	- 1.8677	- 3.2872
x_3'	- 19.8187	+ 3.9658	+ 1.5795	+ 1.5297	+ 1.6874
x_4'	- 7.8000	- 6.3435	- 6.7799	- 9.9069	- 4.3471
x_5'	+ 4.7552	+ 3.4734	+ 1.3614	+ 2.2513	+ 1.6066
x_6'	- 11.1546	- 5.9070	- 8.0399	- 6.2394	- 4.3916
Standard residue	8.2885	8.8318	7.5373	7.8851	5.8737
Series A.					
x_2'	- 6.2652	- 0.4375	- 3.8012	+ 2.7713	- 1.4866
x_3'	- 8.4580	+ 3.4962	+ 8.5846	+ 1.2344	+ 4.5393
x_4'	- 9.3563	- 3.1346	+ 0.0287	- 2.8017	- 0.0108
x_5'	+ 6.3586	+ 2.9879	+ 3.1278	+ 5.6890	+ 4.7814
x_6'	- 9.6516	- 0.1419	- 4.5467	- 2.6659	- 3.8302
Standard residue	6.7575	7.2203	3.6346	6.9627	3.2180
Series AC.					
x_2'	- 11.5996	+ 0.3848	- 4.5246	- 2.7160	- 8.0924
x_3'	- 9.0416	- 7.6392	+ 9.3018	- 8.8744	+ 3.4441
x_4'	- 6.4159	- 1.2530	- 0.0074	+ 0.3297	+ 1.3662
x_5'	+ 5.6062	+ 9.6810	+ 0.0780	+ 9.1830	+ 6.7605
x_6'	- 8.6592	- 5.2549	- 9.5253	- 5.5608	- 6.1892
Standard residue	7.0035	8.5670	5.2210	8.0370	3.4950
Series C.					
x_2'	- 8.7725	- 6.0534	- 7.3962	- 6.8284	- 7.7414
x_3'	- 16.0334	- 14.0367	+ 4.6340	- 13.0049	- 1.6260
x_4'	- 0.3416	+ 3.0592	+ 1.1098	+ 2.4717	+ 2.0922
x_5'	+ 1.4387	+ 11.5523	+ 3.4111	+ 9.3854	+ 6.2905
x_6'	- 6.7297	- 5.0245	- 4.3522	- 4.9600	- 3.9797
Standard residue	6.6235	6.4305	4.3585	6.0970	3.9960

The total sum of squares of deterioration in the yields for the fifty-five years with 54 degrees of freedom, can now be split up into (a) sum of squares of deviations due to deterioration with 1 degree of freedom, (b) sum of squares due to slow changes with 4 degrees of freedom, and (c) the remaining sum of squares due to annual causes with 49 degrees of freedom. The mean sum of squares with 49 degrees of freedom, serves as a basis to test the significance of the deterioration or the slow changes occurring in the various plots. The results are given in Table III.

Table III. *Analysis of variance. Mean squares.*

	Degrees of freedom	Strip 1	Strip 4	Strip 5	Strip 6	Strip 8
Series O.						
Deterioration	1	3.401	23.703	16.847	6.646	9.318
Slow changes	4	83.432	3.790	4.170	3.275	2.490
Annual variation	49	28.835	3.162	3.677	2.433	2.404
Series N.						
Deterioration	1	89.108	0.328	10.542	3.488	10.806
Slow changes	4	150.172	25.731	28.739	36.121	10.902
Annual variation	49	68.704	78.002	56.813	62.179	34.503
Series A.						
Deterioration	1	39.252	0.191	14.449	7.680	2.210
Slow changes	4	73.175	7.749	26.039	12.211	14.534
Annual variation	49	45.657	52.136	13.209	48.479	10.355
Series AC.						
Deterioration	1	134.550	0.148	20.472	7.377	65.487
Slow changes	4	57.336	45.316	44.316	48.529	24.435
Annual variation	49	49.032	73.396	27.260	64.594	12.217
Series C.						
Deterioration	1	76.957	36.644	54.703	46.627	59.928
Slow changes	4	76.138	91.274	13.321	71.984	15.608
Annual variation	49	43.868	41.352	18.998	37.171	15.973

DETERIORATION.

The examination of Table III brings out some very interesting points. It will be observed that all the plots of the O series except the one which receives farmyard manure at the rate of 14 tons per acre, show signs of deterioration. There is a significantly heavy deterioration on plots 4 and 5 of the O series. Plots 6 and 8 of the O series have suffered sensible deterioration, although, as judged by the *z* test the mean squares due to deterioration with 1 degree of freedom are not quite significant when compared with the corresponding mean squares with 49 degrees of freedom for the annual variation. That plot 5 O has suffered more deterioration than 8 O can be partly explained by the fact that it has been supporting a comparatively larger crop of mangolds with the consequent exhaustion of soil nitrogen as well as potash. Besides, as observed already, Swedish turnips have been cultivated since 1852 to 1870, followed by sugar beet till 1876. Turnips are known to be greatly benefitted by the application of superphosphate. The yields of turnips have been consistently much higher on plot 5 O than on plot 8 O. The nitrogen and potash exhaustion is all the more accentuated on plot 5 O. Similarly, a heavy deterioration on plot 4 O can be attributed to the steady exhaustion of soil nitrogen. Plots 8 AC and 8 C again show the deteriora-

tion effect, that on 8 AC, particularly, is significant. It is surprising that plots 5 N, 8 N, 5 A and 8 A do not show deterioration effect. One expects that these plots must have been exhausted of the natural potash supply and, in fact, the unhealthy appearance of the plant is well marked on the plots deficient in potash. They show all signs of an excess of nitrogen—premature death of outer leaves and dark green curled, unhealthy appearance of the remaining tufts of small leaves, which show no signs of completing the growth however prolonged the season may be. Plots 5 and 8 of the nitrate of soda (N) series, however, are comparatively much better. Nitrate of soda seems to be able to do some of the work of the potash, or to release it from the soil. Another interesting point worth noticing is that even on the dunged plots of the N, A, AC and C series the deterioration term has contributed a fairly large sum of squares compared with the annual causes, indicating thereby a steady diminution in the potash supply. This view is further confirmed by the fact that strip 2 which receives potash and superphosphate in addition to the usual quantity of dung, gives a higher yield especially on the A, C and AC series.

SLOW CHANGES.

The inspection of Table III again shows that the slow changes in the mean yield are in the majority of cases not significant. Plot 1 O, however, shows a significant slow change. The remaining dunged plots of the N, A, AC and C series have contributed a fairly large sum of

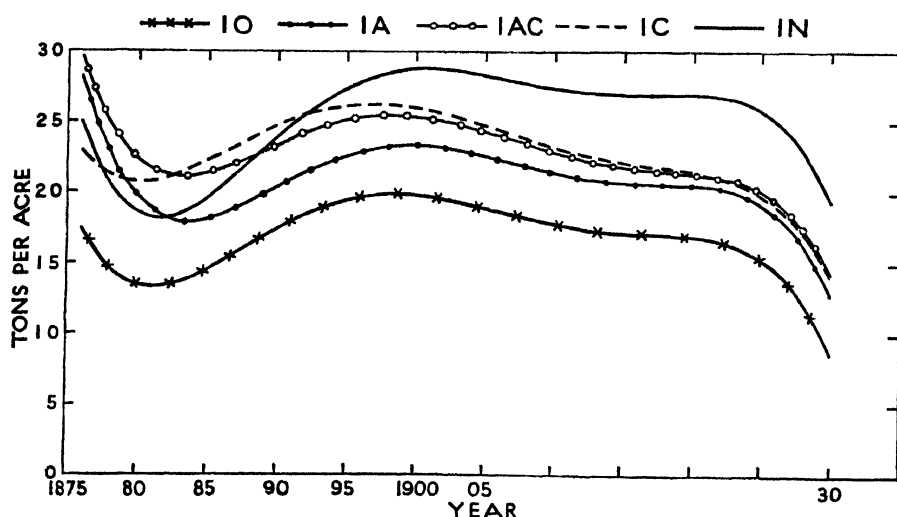


Fig. 1. Plots of Strip 1 (farmyard manure).

squares due to slow changes, but their significance is not statistically demonstrated. So also is the case on plots 4 and 6 of the C series. The polynomial values for the twenty-five plots studied are plotted in Figs. 1 to 5. They show the course of the change in the mean yield of the respective plots. The close similarity of the curves on the dunged plots is very marked indeed. There is a rapid fall in the yield for the first seven or eight years of the experiment, followed by a marked rise for the following fifteen years, the maximum being reached in the year 1900. There is a steady diminution in the yield 1900 onwards, up to about 1922, after which the yields begin to fall off very rapidly except on

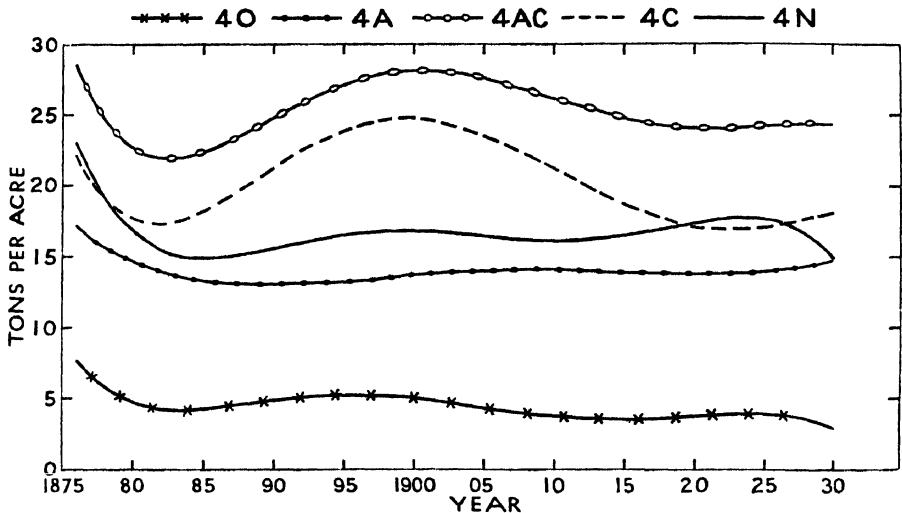


Fig. 2. Plots of Strip 4 (complete minerals).

plots 4 and 6 of the C series where a practically steady level is maintained for about the last eight years of the experiment.

The fall in yield in the early years of the experiment on the dunged plots may partly be attributed to the quality of the dung put on the plots, and partly also due to infestation by weeds. Information is available from the records that in 1879 and 1881 the quality of the dung was comparatively poor. In 1881 it is recorded that the dung used that season was "excessively uneven in character and no doubt in composition also." Similarly, the prevalence of weeds has been recorded from time to time; for instance, in 1881, it is observed that "the dunged plots were covered with weeds like to a meadow, the main bulk are *Stellaria media* (chickweed), intermixed with *Urtica urens* (small nettle), *Senecio vulgaris* (groundsel), *Capsella bursa-pastoris* (shepherd's purse) and *Poa annua* (annual poa)."

168 *Statistical Examination of the Yield of Mangolds*

The fact, however, that other plots also show a steady decline in yield for the first seven or eight years of the experiment indicates that there must be some other cause also operating in bringing about this result. Incidentally, it may be observed that, by the continuous growth of swedes for fifteen seasons, 1856-70, the surface soil had become close owing to the limited and superficial root range and a hard pan was formed below. The condition of the soil consequently became very bad. Sugar beet was, therefore, cultivated for the five successive years, 1871-5. During the first three of the five years of sugar beet, the arrangement of the plots and of the manures was substantially the same as during the preceding years with swedes and subsequent years

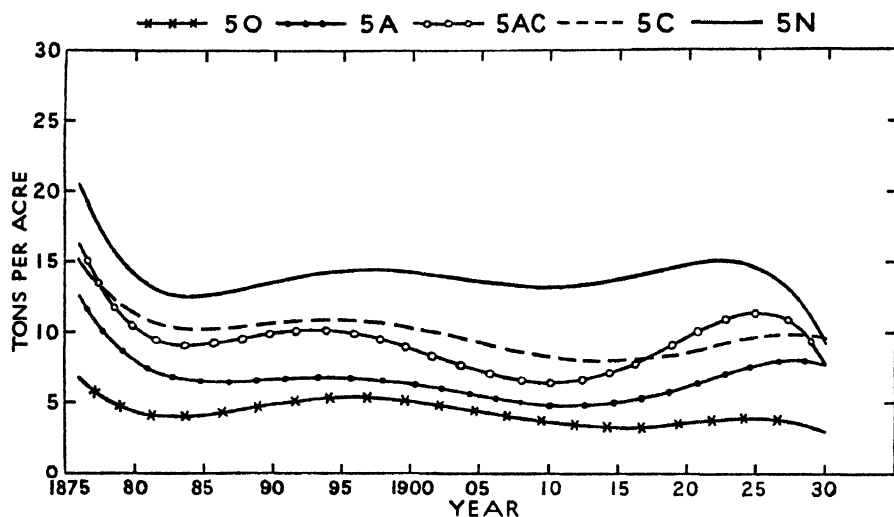


Fig. 3. Plots of Strip 5 (superphosphate).

with the mangolds. But during the last two years of the five, neither farmyard or any other nitrogenous manure was applied. The bad condition of the soil probably persisting for some years, coupled with the withholding of manures, may partly account for the decline in the yield for the earlier years.

The subsequent rise in the yield may partly be explained as due to the change in cultivation. During the earlier years the autumn ploughing was infrequent, but since 1888 onwards it has been a regular feature of the cultivation. An important change was the subsoiling resorted to in the years 1889, 1890 and 1900, and the plots were ploughed deep in the year 1902. The result of such a practice must undoubtedly be the breaking of the soil pan formed below, with the consequent improved

condition of the land. No mention is made of the foulness of the plots at this period in the records and it therefore seems reasonable to suppose that the plots were fairly clean. The improvement in the yields is arrested after 1900, and the yields gradually begin to fall off till 1922 after which there is a heavy decline in the yield. It is recorded that, owing to the thunderstorm on October 1, 1899, water entered Barnfield and flowed over the dunged plots. Also, on February 19, 1900, in consequence of the rapid thaw of a fall of about 15 in. of snow accompanied by some rain a great quantity of surface water accumulated on the portion of the Park adjoining to Barnfield. This found an outlet on to Barnfield, affecting the dunged plots. A similar flooding of surface water on

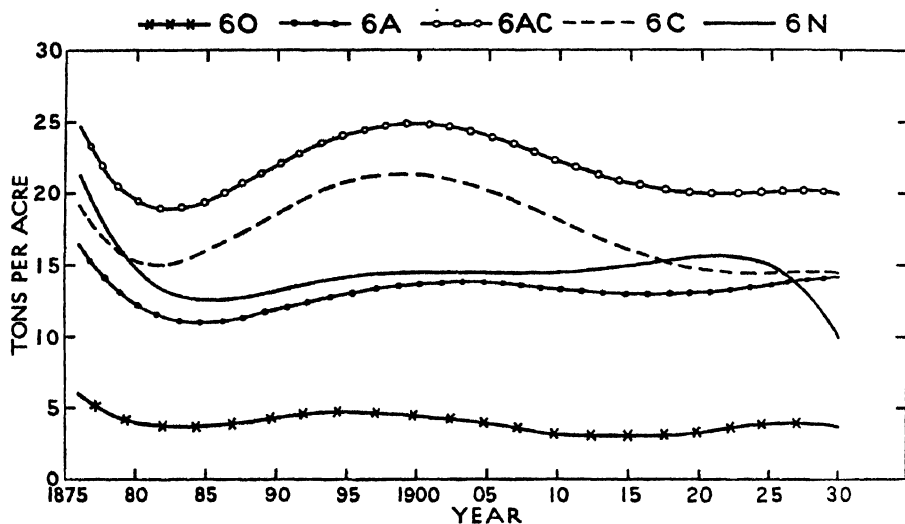


Fig. 4. Plots of Strip 6 (superphosphate and potash).

November 16, 1894, is also recorded. Much of the finer material from the dunged plots must undoubtedly have been removed by this surface flow of water. The rapid fall in yield since 1922 may be largely due to the extremely poor quality of the dung (London manure) that was used for the three years 1922, 1923 and 1924. Of late the dunged plots offer great difficulty in securing a proper tilth. This was first observed in the season of 1925. Similarly for the season 1928 it is recorded "the land worked very badly in the final cultivation but eventually a fair tilth was obtained *with the exception of the dunged strips.*" The fall in yield of the C and AC series plots may also be partly attributed to the fact that for the four years 1917-20 the usual dressing of 2000 lb. of rape cake was omitted.

ANNUAL VARIATION.

The annual variations for the differently treated plots are best shown by the following diagram (Fig. 6) where they are expressed on a relative basis. Deterioration and the slow changes also are shown in this diagram for ease and convenience in comparing them with the differently treated plots. The total sum of squares for each of the three types of variation is first divided by 55, the number of years over which the yields are investigated and also by the square of the mean yield for the respective

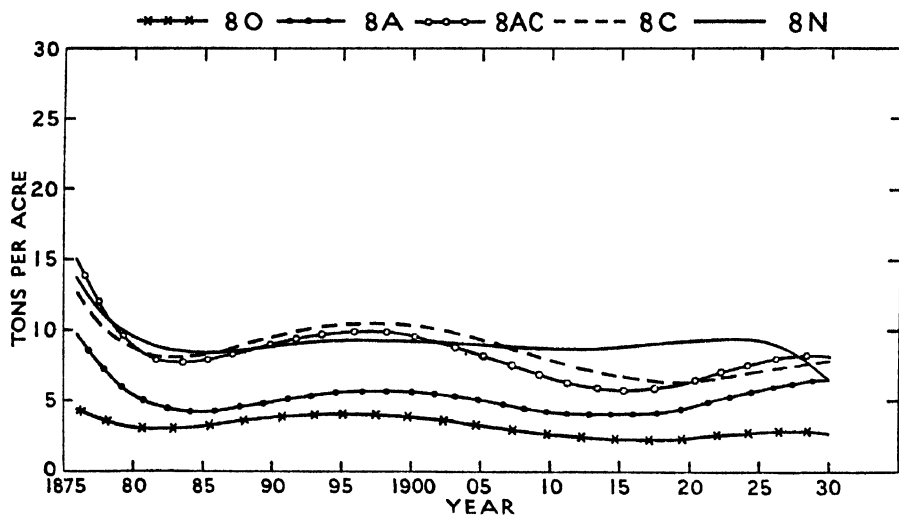


Fig. 5. Plots of Strip 8 (no minerals).

plots. Finally, these figures are expressed in percentage, and are shown diagrammatically in Fig. 6.

The inspection of the diagram reveals striking similarities between some of the plots. It will be observed that the annual variation is small on all the plots receiving organic manures but no nitrogenous fertilisers. Equally is it true of plots receiving potash. The greater relative variance of plots receiving nitrogenous fertilisers is also very obvious. On the basis of the relative annual variance it is now possible to classify the plots into definite groups. They may be classified into two broad groups, viz. (1) plots receiving nitrogenous fertilisers, and (2) plots receiving no nitrogenous fertilisers. Group (2) may now be further classified into various sub-groups, viz: (a) plots receiving farmyard manure or rape cake and potash, (b) plots receiving no organic manures but receiving potash, (c) plots receiving rape cake but no potash, and, finally, (d) plots receiving no organic manures and no potash.

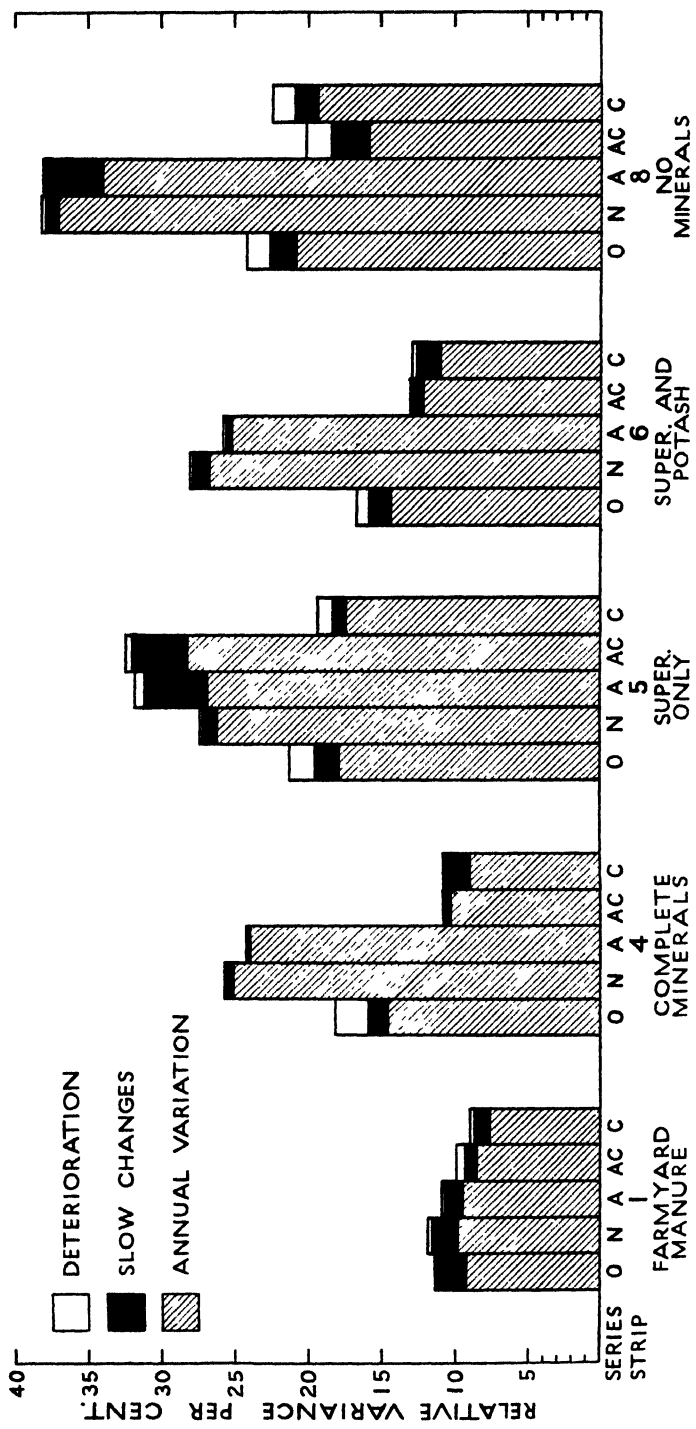


Fig. 6. Causes of variation in the yield of mangolds on Barnfield, Rothamsted.

The greater relative annual variance of those plots which receive nitrogenous fertilisers is well marked. This result is contrary to what has been observed by Miss Mackenzie in her study of the barley crop. The relative variance was greater on the barley plots which did not receive nitrogenous fertilisers. On the Barnfield mangold experiment, plots receiving nitrogenous fertilisers have often shown bad germination with consequent unevenness in number of plants. Some interesting observations are recorded from time to time on the soil emanations. In 1889 a strong smell of chlorine was detected on plots 5 A and 8 A¹. It is also observed that "if a similar chemical action has been going on in the soil during previous years, this may partly account for the less satisfactory germination of the seed on the A series compared with the remainder of the field." Similarly, there is a note on soil emanation on May 30, 1892, which reads "on walking across the land at this date a nitric acid smell was observed on plots 7 N and 8 N, the former being the stronger. A chlorine smell was also noticed on plots 6 A and 8 A, the latter being the stronger. The smell was much the strongest at the junction of 8 N with 8 A, causing quite a pricking sensation in the nose." Such characteristic smells were also observed on the A and the N series in 1895. The usual system is to sow the manures with the seed, but as regards the nitrogenous fertilisers in some years, they are partly sown with the seed and partly top dressed; in others, the whole of the nitrogenous fertilisers are top dressed. On many occasions, the top dressing was followed by a period of about a fortnight in which no rain fell. Evidently, in these years, the young plants must have suffered adversely from the "too concentrated nitrogenous food in direct contact with the young roots," which may partly account for the greater annual variability on the plots receiving nitrogenous fertilisers.

Plots receiving organic manures or potash are less variable. Organic manures and potash act better in seasons of poor growth than in seasons of good growth. These manures have, therefore, a steadying effect on yields, thus tending to level up crop production and consequently reducing the variation in yield from season to season. Strips 5 and 8 which receive no potash have a relatively higher annual variation.

YIELD IN RELATION TO MANURIAL TREATMENT.

Table IV gives the mean yield of roots with the standard error for each plot over a period of fifty-five years. The standard errors are calculated from the sum of squares due to annual variation.

¹ This remarkable observation was confirmed at the time by Dr Miller.

Table IV. *Mean yield of roots in tons per acre over fifty-five years (1876-1930).*

Series	Strip 1 Dung	Strip 4 Complete minerals	Strip 5 Super- phosphate	Strip 6 Super. and potash	Strip 8 No minerals
O	16.71 \pm 0.72	4.41 \pm 0.24	4.28 \pm 0.26	3.90 \pm 0.21	3.21 \pm 0.21
N	24.95 \pm 1.12	16.67 \pm 1.19	13.91 \pm 1.02	14.41 \pm 1.06	9.12 \pm 0.79
A	20.72 \pm 0.91	13.95 \pm 0.97	6.62 \pm 0.49	13.10 \pm 0.94	5.21 \pm 0.43
AC	22.69 \pm 0.94	25.28 \pm 1.16	9.28 \pm 0.70	21.74 \pm 1.08	8.29 \pm 0.47
C	22.68 \pm 0.89	20.30 \pm 0.87	9.90 \pm 0.59	17.43 \pm 0.82	8.58 \pm 0.53

A first inspection of Table IV shows the enormous value of dung in growing mangolds. The yield of mangolds on plot 1 of the O series is about four times as high as those on the other plots of the same series. The importance of farmyard manure in maintaining the fertility of the soil has been already referred to. All the plots of the O series except the dunged plots have suffered a substantial deterioration over the period of years under investigation.

A further inspection of Table IV suggests that it is possible to obtain good crops by the aid of fertilisers containing no organic matter, provided the fertiliser mixture is well balanced in respect of the food ingredients.

The application of nitrogenous manures has undoubtedly given higher yields, even on strip 8 which receives no minerals, but the lower level of yields on this plot in comparison with that on strips 4 and 6 clearly shows that the crop is a very indifferent one for the large amount of nitrogen it receives. Similarly, plots 5 of the A, AC and C series also do not seem to use effectively the large amount of nitrogen supplied to them. In the presence of potassium, however, the plants can effectively use a large amount of nitrogen. Plot 4 O which receives complete minerals, gives without nitrogen only 4.41 tons of roots per acre, which is increased to 13.95 tons by the addition of 86 lb. of nitrogen in the form of ammonium sulphate, and to 16.67 tons per acre by the same amount of nitrogen supplied in the form of sodium nitrate. Application of 98 lb. of nitrogen per acre in rape cake raises the yield to 20.30 tons, which is further increased to 25.28 tons when ammonium sulphate is used in combination with rape cake, supplying in all 184 lb. of nitrogen per acre to the crop. The heaviest dressing of nitrogen has yielded the largest yields on plots supplied with potash, *e.g.* 4 AC and 6 AC, the yield of plot 4 AC being the highest over the entire series, exceeding even the yields given by the dunged plots.

Another interesting result is that, even with a liberal dressing of dung, a further supply of nitrogen in the form of artificial manure, gives

174 *Statistical Examination of the Yield of Mangolds*

a larger increase in the crop. The amount of nitrogen annually supplied to plot 1 O is much greater than is removed by the crop; hence there must be a considerable accumulation of nitrogen from year to year in this plot. Nevertheless, these reserves cannot become active quickly enough for the needs of so rapidly growing a plant as the mangold; hence the increase which is seen when a further addition of nitrogen in a quickly available form is made. The application of nitrogen in the form of rape cake, ammonium sulphate, or a mixture of both, to the dunged plots, results in an increase of about 5 tons, while the application of nitrate of soda has increased the yield by over 8 tons per acre.

The superphosphate plots alone or in combination with nitrogenous manures give only a slight increase in yield over the plots of strip 8 which receives no minerals.

Finally all these results emphasise the close connection between nitrogenous and potassic fertilisers. If nitrogenous fertilisers are dependent for their effectiveness on an adequate supply of potassic fertilisers, so, on the other hand, are the potassic fertilisers dependent on the adequate supply of nitrogenous manures. The superiority of nitrate of soda over ammonium sulphate is also well marked. It may probably be due to the longer and the deeper root system induced by nitrate of soda as against the correspondingly shallow root system developed by ammonium sulphate. The superiority of nitrate of soda is all the more brought out on plots not supplied with potash, viz. 5 and 8. In this case it seems probable that nitrate of soda⁽⁵⁾ is able to do some of the work of potash both by enabling the plant with its extended root range to draw more freely upon reserves of potash in the soil and subsoil, and also by the soda acting itself as a potash substitute.

SUMMARY.

1. Series of yields (root weight) of twenty-five plots of Barnfield mangold field are analysed into components representing (a) deterioration, (b) slow changes other than steady deterioration, (c) annual fluctuations. The two first of these components are exhibited graphically from 1876 to 1930.

2. Yields are well maintained on the dunged strip, except for the last few years. This falling off does not appear in the other strips, and may be due to a falling off in the quality of the farmyard manure in the last five years.

3. On the strip receiving farmyard manure and on that receiving superphosphate the plots receiving nitrate of soda yielded more highly

than any others; on the strips receiving complete minerals, and on that receiving superphosphate and potash, the two plots receiving rape cake in one case, and sulphate of ammonia and rape cake in the other, gave higher yields than nitrate of soda; on the strip receiving no minerals the result is intermediate, there being little to choose between these three plots. On all strips sulphate of ammonia is the least satisfactory of the four nitrogenous dressings tested.

4. In 1876 the land had been already for many years under experiment, and the deterioration from this date is not very striking. The complete minerals and the superphosphate plots of Series O (without nitrogenous manure) show significant deterioration, as does the strip without minerals on Series AC (rape cake and ammonium sulphate). On the strip without minerals the unmanured plot also, and that receiving rape cake both show a strongly suggestive deterioration.

5. Slow changes other than deterioration are unimportant relatively to annual variation except on the dunged plots. Change in the type of cultivation, prevalence of weeds and change in the quality of the manure, are suggested as the probable causes of the slow changes occurring on these plots.

6. Plots receiving organic manures or potash have shown relatively smaller annual variance. Plots receiving nitrogenous fertilisers have a large annual variation.

7. The annual fluctuations will be further studied in connection with rainfall in a later paper.

Finally, it is with the greatest pleasure I thank Dr R. A. Fisher, F.R.S., of the Rothamsted Experimental Station, for his advice and criticism in the preparation of this paper.

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(Received November 23rd, 1932.)

A PRELIMINARY INVESTIGATION OF THE DEVELOPMENT OF STRUCTURAL CONSTITUENTS IN THE BARLEY PLANT.

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(With Three Text-figures.)

INTRODUCTION.

DURING the summer of 1929 a considerable amount of work was carried out in following the changes in composition of barley plants from the seedling stage to maturity. This was undertaken primarily with a view to studying possible inter-relationships of the structural constituents, and to the securing of data which might provide a basis for an investigation of those complex changes loosely known as lignification. Samples were taken weekly, and analyses for various constituents carried out. The results obtained presented a number of interesting features, but seemed hardly sufficient for any generalised conclusions. Very recently, however, a paper appeared in this *Journal* by Malhotra (8) in which is described experiments on the distribution of so-called reserve substances in hard winter wheat at successive growth stages. Since there are certain points in this paper to which exception may be taken, it seems well at this time to publish also some of the analogous results obtained for barley, so that the two may be discussed side by side.

MATERIAL AND METHOD OF SAMPLING.

The barley plants for this investigation were obtained from a small plot rather less than $\frac{1}{4}$ acre in size on Great Harpenden Field, the previous crop being swedes. The area chosen was apparently uniform, but a method of sampling was adopted which would exclude any serious differences in the plant due to variation in soil fertility. The barley, variety Standwell, was sown on March 15 on a seed bed which, owing to a very hard winter, was in excellent condition. A sunny dry March and warm April permitted rapid growth, which was then checked a little in May by wet cool weather. June and July were unusually dry and warm.

The first samples were taken on April 16, a little over 1 month from the date of sowing, and sampling continued weekly till the beginning of August.

So that there might be some information as to the rate of development additional to the dry-weight figures, the number of tillers per 100 plants were counted and, though unsatisfactory as an index of growth, the height of the same number of plants measured and an average figure obtained. Both height measurements and tiller counts were discontinued after the tenth week of sampling.

The method of sampling was suggested by Dr A. R. Clapham. The rows were numbered from one corner of the plot. Two sets of pairs of numbers were selected from Tippett's *Tables of Random Numbers* (12), and the first pair taken to indicate the row and the second the number of paces down that row at which a half-metre sample was to be cut. Edge rows were always neglected, and no sample was subsequently cut at any point immediately adjacent to that from which a sample had previously been taken. The plants were cut off a little below ground-level. The first composite samples that were taken involved as many as 550 seedlings. This number was progressively reduced, but in no case consisted of less than 100 plants. These plants were taken to the laboratory and thoroughly washed to remove any adhering soil. The excess water was removed in a basket centrifuge and the plants placed in an oven at 100° C. for a short period to inactivate enzymes. The first ten samples were then dried in a vacuum oven at 40° C. and finally by a brief period at 100° C. The later samples, when the plant was more nearly mature, after the initial treatment at 100°, were dried in a drying room at a low temperature. In all cases the number of individual plants in the composite sample was first counted, so that when the total dry weight was known, an average figure for plant weight could be obtained. The composite sample was ground in a high-speed mill, to an even size but not too finely.

METHODS OF ANALYSIS.

Of the analyses carried out, the following are relevant at this time.

- (1) Ash.
- (2) Total nitrogen, by Kjeldahl method employing a salicylic-sulphuric acid mixture for digestion.
- (3) Total furfuraldehyde yield by the standard method of distillation with 12 per cent. hydrochloric acid, and precipitation as the phloroglucide, which is then extracted with hot alcohol.

- (4) Cellulose, by the chlorination method¹ of Cross and Bevan (1).
- (5) Furfuraldehyde yield of the "Cross and Bevan cellulose" product.
- (6) Lignin by the 72 per cent. sulphuric acid method due to Ost and Wilkening (10). The product obtained is ashed and the weight of ash deducted.

EXPERIMENTAL RESULTS.

In considering the analytical figures to be presented, it is necessary to bear in mind the extremely rapid growth of the plant in the earlier stages when the dry weight more than doubles in a week. Though the

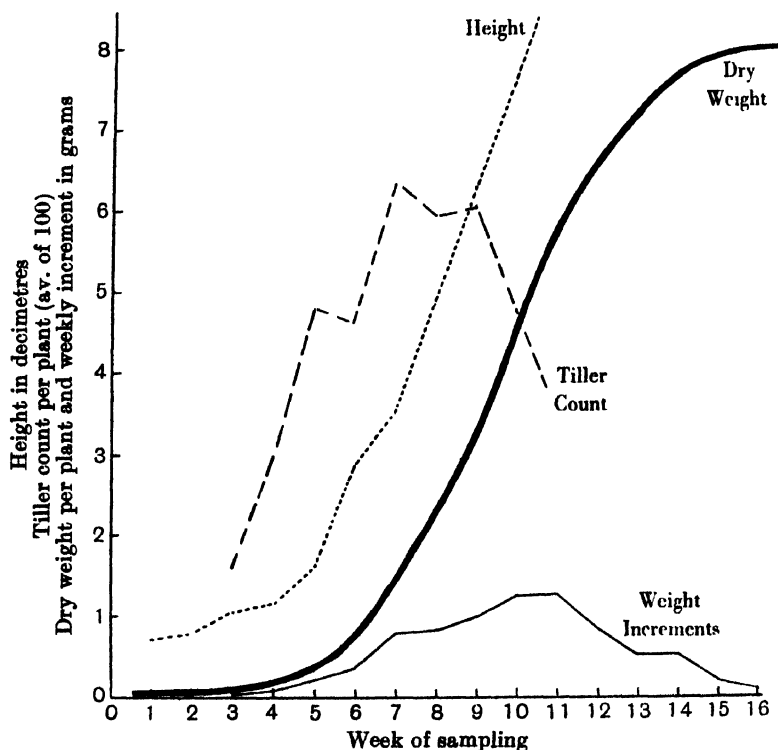


Fig. 1. Growth of the barley plant during season.

weekly increments later are as large or larger, they do not bear the same percentage relationship to the total plant weight. The data bearing on the growth of the plant are given in Table I and are indicated diagram-

¹ This method involves a mild alkaline treatment prior to chlorination—a procedure recently recognised as being objectionable (3) owing to possible effects on the cellulosian fraction.

matically in Fig. 1. The dry-weight figures give a sigmoid curve of the usual type, the point of inflection of the curve lying between Samples 10 and 11. The weekly dry-weight increments have also been plotted, and the period of greatest increase also found to lie between the taking of the tenth and eleventh samples.

The analytical data are given in Table II and in part shown graphically in Figs. 1, 2 and 3.

Table I. *Growth of the barley plant during season.*

Sample No.	Date	Time after sowing. Weeks	Dry weight per plant gm.	No. of plants in composite sample	Tillers per 100 plants	Average height cm.
1	April 16	4	0.038	500	—	7.1
2	" 23	5	0.065	550	33	7.8
3	" 30	6	0.090	450	160	10.5
4	May 7	7	0.160	350	297	11.4
5	" 14	8	0.377	200	480	16.2
6	" 21	9	0.715	135	462	28.5
7	" 28	10	1.48	100	635	35.0
8	June 4	11	2.29	100	595	48.5
9	" 11	12	3.29	100	608	63.0
10	" 18	13	4.54	100	479	76.5
11	" 25	14	5.81	100	—	—
12	July 2	15	6.64	100	—	—
13	" 9	16	7.18	100	—	—
14	" 16	17	7.73	100	—	—
15	" 23	18	7.93	100	—	—
16	" 30	19	8.04	100	—	—

DISCUSSION OF RESULTS.

It will be most convenient to deal with the analytical figures group by group. No direct comparison can, of course, be made with the results obtained by Malhotra (8), since his investigation dealt with autumn-sown wheat, grown under climatic conditions very different from those of the spring-sown barley described in this paper, but attention will be drawn to certain inconsistencies in his analyses.

Ash (Fig. 2). After a slight initial increase in the first three weeks of sampling, the ash content diminished steadily as the plant developed and matured. This is wholly in accordance with the results of Lawes and Gilbert (6). Malhotra's figures show the same general trend, with the addition that there is a fall in the ash content in the winter when growth is checked, followed by a rise in the spring when the young green plant is actively developing.

Protein (total N \times 6.25) (Fig. 2). The figures for protein content show the same tendency as those for ash, namely an initial rise followed by a

Table II. *Analyses of the barley plant at successive periods of growth.*

All figures are expressed as percentage on the dry material.

Sample No.	Ash	Total N	Protein (N x 6.25)	Total furfural yield	Furfural on			Xylan in C. and B. cellulose	"Pure" cellulose	Furfural due to poly-uronides	Pentose* in poly-uronides	Lignin (ash free)
					Cellulose (C. and B.)	100 gm. C. and B. cellulose	on 100 gm. C. and B. cellulose					
1	13.91	4.45	27.82	8.38	29.34	7.22	2.12	3.30	26.04	6.26	13.28	14.4
2	14.04	4.37	27.32	8.54	31.40	7.94	2.49	3.89	27.51	6.05	12.83	14.9
3	14.44	5.28	33.00	7.06	37.69	8.54	3.22	5.01	32.68	3.84	8.18	14.7
4	11.66	5.86	36.63	6.76	36.83	8.35	3.07	4.78	32.05	3.69	7.85	14.6
5	11.54	4.74	29.63	6.95	34.84	8.42	2.93	4.56	30.28	4.02	8.54	14.9
6	11.04	3.17	19.82	6.11	39.60	8.54	3.38	5.26	34.34	2.73	5.80	15.6
7	10.96	2.55	15.93	8.02	41.22	8.40	3.46	5.38	35.84	4.56	9.71	15.9
8	9.31	1.58	9.88	10.15	42.30	10.90	4.61	7.16	35.14	5.54	11.76	16.1
9	9.05	1.26	7.87	10.11	46.13	11.60	5.35	8.31	37.82	4.76	10.10	18.3
10	8.47	1.18	7.37	10.23	46.90	11.48	5.39	8.38	38.52	4.84	10.29	18.9
11	6.92	1.03	6.44	10.79	46.40	15.10	7.00	10.84	35.56	3.79	8.08	18.5
12	7.18	0.83	5.19	11.20	46.35	18.00	8.34	12.93	33.42	2.86	6.11	18.5
13	5.86	0.68	4.25	10.58	45.92	16.50	7.57	11.75	34.17	3.01	6.43	19.7
14	5.82	0.62	3.87	10.63	46.90	15.50	7.27	11.28	35.62	3.36	7.16	18.5
15	5.47	0.57	3.56	10.74	51.09	14.20	7.25	11.25	39.84	3.49	7.43	17.6
16	5.40	0.56	3.50	11.00	52.88	12.64	6.68	10.63	42.25	4.32	9.19	17.4

* Calculated as arabinose.

steady fall. The highly nitrogenous composition of young green plants is emphasised, Sample 4 containing as much as 36.6 per cent. In both Samples 3 and 4 protein and ash together account for nearly half the plant tissues. Similarly the total nitrogen figures given by Malhotra⁽⁸⁾ follow the ash content, falling in the winter and rising again in the spring. However for his last two samples, when the straw is approaching maturity, he quotes as the nitrogen content 4.6 per cent., equivalent to 28.7 per cent. protein. This is vastly higher than the figures usually recorded for wheat, even when considerable quantities of nitrogenous fertiliser are applied. As little as 0.21 per cent. N has been recorded, with a general average about 0.5 per cent. Shaw and Wright⁽¹¹⁾, in analysing the maize plant, similarly show a steady fall to a final N content of about 1 per cent.

Cellulose (Fig. 2). The product obtained by the Cross and Bevan method cannot be regarded as consisting of pure cellulose alone, but is always found to be intimately associated with other polysaccharide material. These associated polysaccharides have been termed by Hawley and Norman⁽³⁾ "cellulosans," and may only be removed by extraction, with the greatest difficulty. It seems probable that the two must be considered together as composing the natural cellulosic fabric of the plant; indeed Cross and Bevan's original definition of the word cellulose would so regard it. In the case of the cereals, the associated cellulosan appears to be composed of pentose units and in all cases that have been examined the pentose has been found to be xylose. By determining, therefore, the furfuraldehyde yield of the Cross and Bevan cellulose product, it is possible to determine what part of that product consists of true cellulose, pure in the chemical sense, and what part is cellulosan. The relationship between these two has been peculiarly interesting in these development studies.

Considering first the Cross and Bevan cellulose figures, from a low figure, under 30 per cent., in the young seedling, the content rises to 53 per cent. The rise, however, is not even or regular. There is an initial peak at the third week of sampling, followed by an apparent fall, and then a fairly rapid rise to the ninth week, after which cellulose production proceeds proportionately to the increase in plant weight and a position of relative stability is maintained for 5 weeks. In the closing stages of maturity the cellulose content again rises. If, however, the cellulosan content is considered, and calculated as xylan from the furfuraldehyde yield of the Cross and Bevan cellulose product, it will be seen that the ratio of "pure" cellulose to cellulosan is not a constant one, but changes

as development proceeds. In the youngest seedling the $\frac{\text{"pure" cellulose}}{\text{cellulosan (xylan)}}$ ratio is approximately 8, and this figure steadily lessens as the total cellulose content increases, until in Samples 9 and 10 the ratio is about 4.6. In other words, as the plant increases in age, the natural cellulose contains more cellulosan and less true cellulose. This tendency becomes much more marked after this point, and it is significant that this also is just the point of inflection of the growth curve after which growth is slackening and the weekly growth increments fall off. Cellulosan pro-

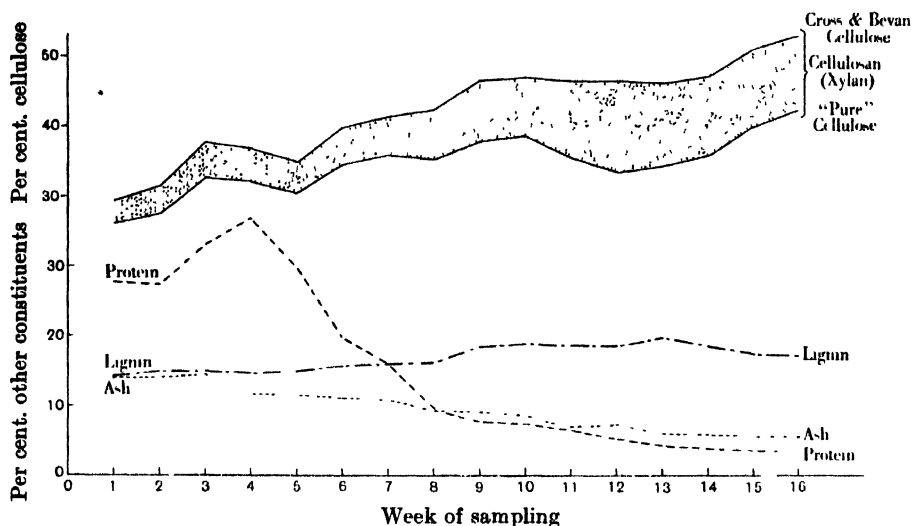


Fig. 2. Composition of barley plant.

duction increases so much that the content of "pure" cellulose actually appears to fall, and in the twelfth sample the $\frac{\text{cellulose}}{\text{cellulosan}}$ ratio is as low as 2.6. From this time it slowly widens again, and in Sample 15 is 3.5. The differences between Samples 15 and 16 are a little surprising for, although there is very little change in plant weight, there is an appreciable increase in Cross and Bevan cellulose content. When these series of figures are examined on the basis of the quantities of each constituent actually present per plant, it is found that the observed widening in the ratio in the closing stages is apparently due to the production of "pure" cellulose alone, since, after Sample 12, the quantity of xylan in the plant remains virtually constant. This may possibly be caused by a balance between transformation and replacement, but at present no evidence bearing on this point is available. Nothing is known of the mechanism of

cellulose production in the plant, but for reasons which have been given elsewhere it seems likely that the cellulosan and pure cellulose are produced at the same time and by the same agency. The balance between the two changes during growth, at first steadily and then more rapidly.

Lignin (Fig. 2). The method of estimation adopted, involving the use of 72 per cent. sulphuric acid, is far from satisfactory, though generally employed, and the figures are presented with some reserve. It is certain that the lignin is changed by this treatment and by no means certain that errors do not occur when, along with the carbohydrate material, there is also protein present, since humin bodies may be formed. That in the young green seedling there should be as much as 15 per cent. lignin was not expected. This figure rises steadily, until a month before maturity there is nearly 20 per cent. present, after which there is a slight fall. This fall is no doubt due to increased starch production and the filling out of the grain making the proportion of straw in the plant correspondingly lower.

Hemicelluloses. An accurate method for the estimation of the hemicelluloses is urgently required. Objections, often very serious, can be raised to all the methods proposed at present. Apart from the cellulosans, the members of this group consist usually of mixed monose units, a hexose, a pentose and a uronic acid. Because of the presence of the latter these may suitably be known as polyuronides. While it is possible accurately to estimate the pentose and uronic acid units, the hexose units present are elusive. A further difficulty arises in that the polyuronides vary considerably in composition according to the age and nature of the tissue. Until such time as a comprehensive investigation of this group is made, it is well to be very cautious in dealing with analyses involving them.

In this investigation the only information obtained on the variation in amounts of the polyuronides deals with the pentose units involved. The difference between the total furfuraldehyde yield and that due to the cellulosan in the Cross and Bevan cellulose may be taken as due to the pentose and uronic acid units in the polyuronides. The uronic acid content throughout was very low and no correction has been applied for the presence of such units.

Malhotra⁽⁷⁾ has described a method for the estimation of hemicelluloses, and employed it in his developmental studies on the wheat plant⁽⁸⁾. It involves an acid hydrolysis (2.5 per cent. hydrochloric acid for 4 hours) and titration of the reducing sugars formed, which are then calculated as dextrose. Incidentally this sugar is very rarely found in

polyuronides. The objections to acid hydrolysis as a method of estimation of the hemicelluloses have recently been given fully by Hawley and Norman(3). Since that time it has been found that the major part of the cellulosan of straw is also very readily hydrolysed by dilute acid, and would therefore appear as sugar in the hydrolysate obtained by Malhotra(8). His claim, therefore, that the figures given by him represent the reserve hemicelluloses of the wheat plant cannot be accepted. In any case it is very doubtful whether either class of hemicellulose, the cellulosan or the polyuronicide, may be regarded as a reserve in the wheat or barley plant. There is reason to suppose that the polyuronides are

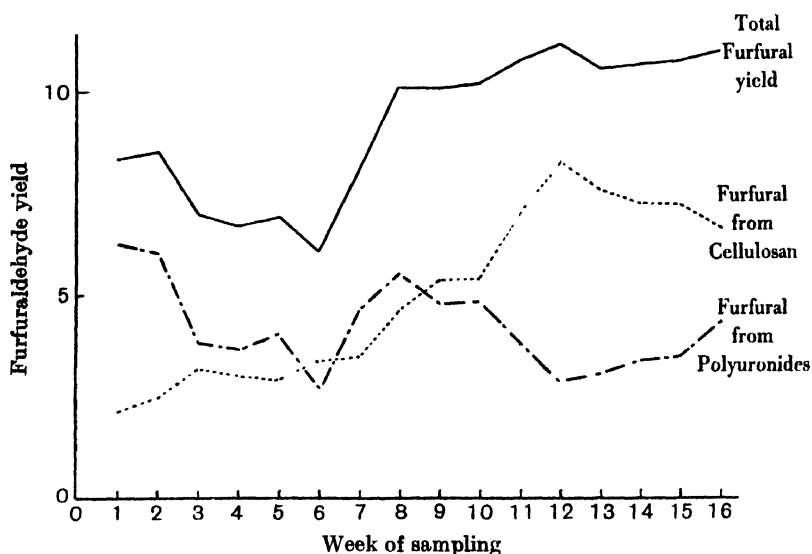


Fig. 3. Furfuraldehyde yield of barley plant.

the least stable type of structural polysaccharide, but their precise rôle in cell metabolism is completely unknown.

The figures obtained for pentose content of the polyuronides of the barley plant are given in Table II, and exhibit considerable variation with increasing age. The young seedling contains more than at any subsequent period. There is a distinct fall after Sample 10 had been taken, and this, as mentioned earlier, is the point at which growth is slacking. In the period approaching maturity there is again a definite rise.

It will be seen that a figure for total "pentosan" obtained from the total yield of furfuraldehyde would be very misleading, since it would tend to indicate an almost constant quantity present all throughout the

later periods of growth. This will be seen clearly in Fig. 3, in which is plotted the total furfuraldehyde, the furfuraldehyde due to cellulosan, and that from the pentose units in the polyuronides. In the young plant the major part of the pentose material is not associated with the cellulose, as cellulosan, but is in the polyuronide group, while later as the plant reaches maturity the reverse is the case. Previous workers have not recognised this, but have shown that there is a gross increase in total "pentosan" as growth proceeds. This has been done by Ver Hulst, Peterson and Fred⁽⁵⁾ in the case of the maize plant, and Dustman and Schriver⁽²⁾ for *Ambrosia trifida*.

Sugars. Since this investigation was primarily concerned with the structural constituents, free-soluble sugars were not determined. Malhotra⁽⁸⁾, however, in the wheat plant has carried out this determination, and quotes figures which must be in error, stating there to be as much as 34 per cent. soluble sugar in the mature plant and even 40 per cent. some weeks before maturity. The figures given by Newton and Brown⁽⁹⁾ for several varieties of winter wheat, though not carried through right to maturity, are of a much lower order. Without taking into account two such important constituents as cellulose and lignin, his analyses in several cases total more than 100 per cent.

DISCUSSION.

The results presented in this paper are insufficient for any generalisations, but provide a basis for a further examination of the many problems involved. It is questionable whether the plant should again be considered as a whole, or whether particular regions should not be selected for examination as, for example, leaves, a certain internode, or the ear. To treat the plant as a whole may lead to incorrect conclusions, particularly when the grain is filling, as this may produce an apparent depression of some constituents. The final fall in lignin content is no doubt due to this cause. Conversely, the ultimate increase in cellulose observed must be even greater than it appears to be. The importance of sampling weekly may readily be seen.

Probably the most interesting feature of the results is the marked changes observed as growth slackened—the very definite increase in the production of cellulosan as compared with the true cellulose, and at the same time a marked fall in the pentose material of the polyuronides. Whether these two observations are in any way related, it is not possible to say, though it seems rather doubtful. The transformation from a highly proteinous condition, when the strength of the plant is largely

dependent on cell turgidity, to the later and predominantly carbohydrate state in which the tissues have themselves mechanical strength is a very remarkable one. The increase in cellulose content would appear to be more important in this connection than that of lignin, and it seems possible that the theories as to the paramount rôle of lignin in conferring mechanical strength may be not so well supported by the facts as has been supposed. The recent work of Hawley and Wiertelak⁽⁴⁾ will focus attention on the probable carbohydrate origin of lignin. Pentose material, particularly that associated with cellulose as cellulosan, was converted to some lignin-like material by heat treatment. It cannot be said that in the present work any relationship between the two was noticeable; indeed, the period at which the lignin increased was also that when considerable increase was noted in the pentose material, both as cellulosan and in the polyuronides. Nevertheless this cannot be taken as evidence against the theory of Hawley and Wiertelak, since the growth increments at that time were sufficiently large to confuse the issue. This is always likely to be the case in studies of this type, and the final solution of the problems of genesis and inter-relationships of the structural constituents will no doubt lie in a combination of experiments, both *in vitro* and *in vivo*.

SUMMARY.

1. Barley plants, carefully sampled, were harvested weekly during the season. Growth measurements were made and various analyses carried out on the dried material.

2. Both ash and protein showed an initial increase followed by a steady fall as development proceeded.

3. The Cross and Bevan cellulose fraction, which may be taken as the natural cellulosic fabric of the plant, increased from 30 to 53 per cent., showing an initial peak, and later a stationary period.

4. The amount of cellulosan (or associated polysaccharide) in the cellulose increased with development, and markedly so after the point at which growth increments lessened.¹

5. Lignin increased steadily until the last week or so, the fall then probably being due to the increased weight of the grain with respect to the straw.

6. Only the pentose groups of the hemicelluloses were determined. The amount present was irregular but was lower in the mature plant

¹ In the later stages the quantity remained constant and because of the continuing production of pure cellulose, the $\frac{\text{cellulose}}{\text{cellulosan}}$ ratio widened.

throughout. The seed used was Plumage-Archer, supplied by Messrs. W. Hasler of Dunmow, threshed from a field personally inspected by Mr. Hasler and regarded by him as being of a high order of purity.

The supply of manures was organised by the Fertiliser Manufacturers' Association.

The experimental scheme comprised five plots, which were as follows :—

- 1.—No manure.
- 2.—Complete artificials: 1 cwt. sulphate of ammonia; 3 cwt. superphosphate; $1\frac{1}{2}$ cwt. sulphate of potash per acre.
- 3.—Artificials without potash: 1 cwt. sulphate of ammonia; 3 cwt. superphosphate per acre.
- 4.—Artificials without phosphate: 1 cwt. sulphate of ammonia; $1\frac{1}{2}$ cwt. sulphate of potash per acre.
- 5.—Artificials without nitrogen: 3 cwt. superphosphate; $1\frac{1}{2}$ cwt. sulphate of potash per acre.

We should like to have duplicated these plots, but unfortunately it is difficult to get farmers properly to carry out as many as ten separate plot experiments, and the gain in symmetry of design would have been more than counter-balanced by the loss of accuracy in working. We therefore had single plots only. It will be seen later that checks can be applied to three plots out of five, and a satisfactory result is obtained in all cases where the previous treatment had been uniform (Series I), but no satisfactory result is obtained where the treatment had varied (Series II). While we cannot precisely estimate the experimental error in Series I (on which discussion is mainly concentrated), there is no reason to suppose that it is large. In well conducted single plot experiments of this type it would often be of the order of 5 to 10 per cent. for a single season.

There are thirteen centres :—

Eastern Side—

- 1.—Rothamsted Experimental Station, Harpenden, Herts.
- 2.—Beds. Woburn Experimental Farm. Dr. J. A. Voelcker.
- 3.—Essex. Dunmow. W. Hasler, Esq., Barnston Lodge Farm (G. Bellfield, Esq.).
- 4.—Suffolk. Howes Farm, Martlesham. Rt. Hon. E. G. Pretyma, Esq., Orwell Park.
- 5.—Norfolk. East Dereham. B. Hill, Esq., Hall Farm, Gressenhall.
- 6.—Peterborough. Eye. S. M. Eger, Esq., Northholme.

- 7.—Lincs. Wellingore. G. H. Nevile, Esq.
- 8.—Lincs. Walcott. C. Bembridge, Esq. !
- 9.—Lincs. Cawkwell. Scamblesby. A. E. Davy, Esq.
- 10.—East Lothian. Barneyhill. Sir Harry Hope.

Western Side—

- 11.—Shropshire. Eyton-on-Severn. E. Craig Tanner, Esq.
- 12.—Somerset. Milverton. W. H. Edwards, Esq.
- 13.—Wiltshire. Warminster. E. S. Beaven, Esq.

This being the first season and the work not having been begun till early in 1922, it was not always possible to take full precautions in regard to uniformity of the land, and in a few cases there had been some cross-cropping. The precise history of the land was in all cases known and these cross-cropped centres have given us valuable information as regards residual effects of manures and soil treatment on the growth of barley.

The Season.

The season of 1922 was in many respects peculiar. From the time of sowing to the latter part of June there was little rain and the weather was hot; these conditions were, of course, unfavourable to plant growth and to fertiliser action, less unfavourable, however, to potash than to phosphates. In July there was heavy rainfall with low temperature, and this wet, sunless weather continued till the end of the season.

The effect on the yield of grain was distinctly marked, but the effect on its quality was disastrous. An experienced buyer declared that it was the worst season he had encountered in 30 years.

The details of the season in certain centres are given in Appendix IV.

Lateness of Starting—Special feature of the year.

For various reasons the field experiments were started later than could have been wished; there were delays in finding suitable farms, in arranging details with the farmers and in getting deliveries of seed, manures, etc. At certain centres the farmers considered the sowing was as much as 10 days, or even 14 days later than was desirable. In view of the subsequent weather conditions, it is unlikely that the delay was seriously prejudicial, but in any case, it should not recur now that the scheme is in working order.

The yields at the various centres are given in detail in Appendix III and summarised in Table 1.

TABLE 1.—YIELDS OF DRESSED GRAIN.

SERIES I.—Centres where the previous treatment and the soil conditions were as uniform as practicable.

DRESSED GRAIN (HEAD CORN) PER ACRE.*

Soil formation.	Heavy soils.	Loams.				Light.	Very Light.		Fen.
	Rothamsted.	Cawkwell. Scamblesby.	Wellington.	Barneyhill.	Milverton.		Woburn.	Orwell Park.	
	Clay overlying chalk.	Loam overlying chalk.	Inferior oolite.	Trias.	Trias.	Sand over chalk.			Lower greensand.	Blown sand.	Fen.
No manure	25.8	25.2	36.1	78.5	26.0	36.7	42.5	16.2	56.9
Complete manure	32.6†	30.9	39.0	89.0	—	41.0	44.7	21.6	60.3
No potash	27.0	22.6	43.5	84.0	27.2‡	42.0	41.8	24.6	58.7
No phosphate	33.0	28.8	40.5	85.0	—	36.0	39.9	27.9	61.3
No nitrogen	28.2	23.1	37.3	75.5	23.3	30.0	45.0	18.2	60.8

* In all cases except Woburn, the bushels are weighed quantities of 56 lb. At Woburn they are measured. The weighed bushels are given in Appendix III.

† Two check plots, one using potassium chloride in place of potassium sulphate, and the other ammonium chloride in place of ammonium sulphate, gave respectively 31.0 and 32.5 bushels per acre.

‡ No nitrogen was supplied here.

Stated as percentages the results are for TOTAL GRAIN—

	Rothamsted.	Cawkwell.	Wellington.	Barneyhill.	Milverton.	Dereham.	Woburn.	Orwell Park.	Walcott.
No manure . .	100	100	100	100	100	100	100	100	100
Complete manure . .	122	123	109	113	—	110	104	134	106
No potash . .	104	93	120	107	—	114	96	152	105
No phosphate . .	124	115	112	108	—	97	92	173	107
No nitrogen	108	91	104	96	90	81	100	113	105
For DRESSED GRAIN—									
No manure	100	100	100	100	100	100	100	100	100
Complete manure . .	127	122	108	113	—	112	103	134	106
No potash	105	90	121	107	—	114	95	152	103
No phosphate . .	128	114	112	108	—	98	92	173	108
No nitrogen	109	92	104	96	90	82	100	113	107

The first point to notice is that the yields on the unmanured plots vary from 16·2 to 78·5 bushels of dressed grain, but that the average is distinctly above the average for the whole country. This variation is remarkably wide. The extreme soils—the heavy soil at Rothamsted and at Cawkwell and the very light soil at Orwell Park—give the lowest yields, though Rothamsted and Cawkwell stand higher than Orwell Park. The best yields are obtained on the magnificent soil of Barneyhill, and on the fen soil at Walcott. We shall see later that in all these cases there are considerable differences in quality.

The influence of the complete fertiliser is in all cases to raise the yield per acre ; the increases over the unmanured plots being :—

		Rothamsted.	Cawkwell.	Wellingore.	Barneyhill.
Bushels	....	6·8	5·7	2·9	10·5
Per cent	....	27	22	8	13
		Dereham.	Woburn.	Orwell Park.	Walcott.
Bushels	....	4·3	2·2	5·4	3·4
Per cent.	....	12	3	34	6

The 89 bushels obtained on the completely manured plot at Barneyhill is among the highest on record.

The omission of **potash** has, out of the eight cases, been without effect in two ; it reduced the yield in four cases ; but apparently raised it in two cases ; the effect of omitting **phosphate** has been without effect in three cases ; it has reduced the yield in four cases and increased it in one ; while the omission of **nitrogen** was without effect in two cases, but led to decreased yields in six cases. (Table 2.)

The nitrogen effect is quite normal ; the average effect of the 1 cwt. sulphate of ammonia over the seven farms has been to increase the yield by nearly $5\frac{1}{2}$ bushels per acre. The average expected over a run of soils and seasons is about $6\frac{1}{2}$ bushels. In two cases the nitrogen was without action ; the Walcott fen farm, which is quite in accordance with experience, and the Woburn soil, where ordinarily the nitrogen acts quite well, but crops of barley for reasons of soil and climate would

TABLE 2.—EFFECT OF MANURING ON YIELDS.

CHANGE IN BUSHELS PER ACRE IN PLOTS :—

	Rothamsted.	Cawwell.	Wellingore.	Barneyhill.	Dereham.	Woburn.	Orwell Park.	Walcott.
Omitting—								
Potash ...	-5.6	-8.3	+5.5	-5.0	Nil.	-2.9	+3.0	Nil.
Phosphate ...	Nil.	-2.1	Nil.	-4.0	-5.0	-4.8	+6.3	Nil.
Nitrogen ...	-4.4	-7.8	-1.7	-13.5	-11.0	Nil.	-3.4	Nil.

CHANGE IN PERCENTAGE INCREASE OF YIELD IN PLOTS :—

	Rothamsted.	Cawwell.	Wellingore.	East Lothian.	Dereham.	Woburn.	Orwell Park.	Walcott.
Omitting—								
Potash ...	-22	-32	+13	-6	+2	-8	+18	-3
Phosphate ...	+1	-8	+4	-5	-14	-11	+39	+2
Nitrogen ...	-18	-30	-4	-17	-30	-3	-21	+1

As against complete manure in each case.

rarely exceed 45 bushels per acre ; this level is already attained without nitrogenous manures. Omitting these two from the average the increase becomes 7 bushels. This regular and normal behaviour of nitrogen shows that the plots were well chosen and the figures tolerably reliable.

An independent check is obtained by comparing the no nitrogen plot with the unmanured. Normally a small increase is expected excepting where the yield of the unmanured is high, when no change might occur. Actually an increase of from 5 per cent. to 10 per cent. is obtained in four cases where the unmanured does not give high yields ; there was no effect at Woburn where the unmanured gave the good yield (for that farm) of 42·5 bushels, and at Barneyhill, where the unmanured plot gave the very high yield of 78·5 bushels per acre. (Differences of 5 per cent. or less are in any case negligible.) We are thus left with only two centres : Cawkwell, where the recorded falling off is 9 per cent., and which might be represented either as experimental error or a thinning of the soil from Plot 1 to Plot 5, and Dereham, where Plot 5 gives a low result which we cannot explain.

Omission of phosphates might be expected to have no effect on the yield if there were a sufficiency of these substances in the soil as a result of previous treatment or of natural richness, or it might depress the yield if insufficient were present. Both these cases occur ; there was no effect at Rothamsted, Wellingore or Walcott, and there was a depression at Cawkwell, Dereham and possibly Barneyhill. With the exception of Rothamsted, to which further reference will be made, these results might easily be normal. Two results remain : Woburn, where a depression below the unmanured is recorded, and Orwell Park, where a large increase is obtained.

Phosphates have the effect of hastening the ripening of cereal crops. As a rule this property helps very much on heavy soils and on loams, but it is less needed on sands, and indeed may do actual harm, because on these soils, ripening is already premature and the crop suffers in consequence. This appears to be what happened on the light sand at Orwell Park ; but it was not expected that phosphate would be without action at Rothamsted, yet such is the case. Normally, phosphates have a marked effect on barley at Rothamsted, stimulating both early root action and early ripening. For some weeks after sowing, the phosphate showed its usual beneficial action, but towards the end of the drought, it was seen that the completely manured plot was beginning to turn yellow prematurely, while the "no-phosphate" plot kept its colour better. When the rain came in July it was too late to stop the maturing process

on the completely manured plot, and the result was a loss of all the advantage gained in the early days over the "no-phosphate" plot. It was apparently the same action as at Orwell Park, but not carried quite so far. The failure of phosphates at Wellingore may have arisen from the same cause. At Walcott, the comparative ineffectiveness of the manures may be due to the high productiveness of the unmanured land.

The action of potash at Rothamsted was more marked than in a normal moist season; it was, indeed, as good as that of nitrogen. All through the drought the "no-potash" plots were behind the "complete manured" in growth. It is, however, quite typical of potash to help the plant in dry conditions. At Cawkwell, Woburn and Barneyhill potash was also distinctly effective; except in the latter instance it was, as at Rothamsted, as effective as nitrogen, and no doubt for the same reason. At Derham and Walcott potash was without appreciable effect—it was possibly of slight advantage at Walcott—but at Wellingore, for some reason we cannot at present explain,* the addition of potash seemed to depress the crop; the "no-potash" plot in June had a darker colour than the rest, though elsewhere this plot was usually lighter in colour.

These results show quite clearly that no one complete manure could be recommended for barley; some of the ingredients appear to be capable of doing actual harm in special circumstances.

We hope that a continuance of these experiments will enable us to arrive at the factors determining the reasons for the effectiveness of the various ingredients so that we can advise farmers much more definitely than at present what types of manuring to use in order to obtain the best results.

At Milverton the scheme was modified in two directions; the manures were applied as top dressings two months after sowing; and the nitrogenous dressing was omitted, because the land had been so well treated in the preceding year for cabbages, that it was feared the barley would go down if nitrogenous manures were supplied. The result showed that this was not the case; the yields were low and not affected by the manures; there is little doubt that the addition of nitrogen would have brought out differences. It will be seen later that there were important differences in quality on the various plots which may be associated with the manuring.

Though Mr. Beaven's experiments are not strictly on the same plan

* It is possible that the potassium salt may have caused or increased acidity in the soil.

as the foregoing his results are included here, by his kind permission, for the sake of completeness. There were six plots—an untreated one at each end with four treated ones in between. The yields from the plots are as follows :—

							Bushels per acre.
Untreated	...	...	...	...	...	...	46.2
Nitrogen only	...	...	...	...	...	...	43.8
No potash	...	...	...	...	...	...	40.8
No nitrogen	...	...	...	...	...	...	35.1
Complete manure	...	...	...	...	...	...	39.4
Untreated	...	...	...	...	...	...	38.3

It will be observed that there is a considerable difference between the two untreated plots, and that even if the mean is taken the yields still come out higher than those receiving manure. Mr. Beaven attributes this variation, and no doubt rightly, to variation in soil. His experiment is concerned more with a comparison of the behaviour of two different varieties than with manuring, and his methods tend to reduce soil variations to a minimum.

SERIES 2.—Centres where there was some Cross-Cropping.

At three centres there had been some cross-cropping in the previous year. The barley was grown after the root break, but there had been a lack of uniformity in the cropping, though the field itself was level and apparently uniform. The experiment was completed so as to show for our future guidance whether the effects would persist or whether, after the heavy winter rainfall (December, 1921, to February, 1922), they would be entirely swamped by the manuring. The results were :—

	Medium Loams.				Black Soil.	
	Eyton on Severn.		Dunmow.		Eye, Peterboro'.	
	Previous treatment.	Yield.	Previous treatment.	Yield.	Previous treatment.	Yield.
No manure	Vetches	36.0	Potatoes on 2/3 Plot 1	51.0	F.Y.M.*	39.5
Complete manure	Vetches	28.0	Mangolds	49.5	Much less F.Y.M.	43.5
No potash	Common turnips Wholearea lightly folded	45.2	Mangolds	47.0	No F.Y.M.	44.1
No phosphate		44.5	Kohl-rabi	49.0	No F.Y.M.	50.9
No nitrogen		48.0	Kohl-rabi	45.0	No F.Y.M.	59.1

* F.Y.M. = Farm Yard Manure.

It is evident that the previous cropping had much affected the yield, obscuring the relationships shown in the previous set. At no centre do the plots conform to the tests mentioned elsewhere, nor should they do so; this affords additional evidence of value of the tests and the reliability of Series I.

At Eyton the "complete manure" stood out best throughout most of the growing season, but at harvest, it showed a remarkably low yield. It may be, as Mr. Craig Tanner suggested, that the nitrogen used actually depressed the yield of grain, but if this is the explanation it is difficult to understand why the "complete manure" plot should be below the "no-phosphate" and the "no-potash" plots. Eye gave somewhat similar results, and the possibility must be considered.

At Dunmow the manuring and cultivation over the whole field had been the same for the crop preceding the barley, but potatoes had been grown on two-thirds of Plot 1. It is possible that more residual manure remained here than on the others, though the appearance of the crop through the growing season, right up to August 18th, indicated that complete manure would give the largest crop. It is also possible that the differences in yield are apparent only and not real, and that in spite of the manuring all the crops were brought to a uniform level by the season.

Influence on the market value of the Barley.

The barleys were all judged under rigidly comparable conditions by a Sub-Committee, consisting of Messrs. Cherry-Downes, Lancaster and Reid. A sample from each plot was handed to the judges under a distinguishing number, and the judges had no means of knowing from which farm, or even from which county, any sample was drawn. The judging having been carried out under these conditions the results obtained appear to be remarkable, and ought to be more or less reliable. The barley values are given in Table 3.

The values vary from 30s. to 65s., but at each centre they run very much on one level.

The season was deplorably bad for quality, and except in the case of Orwell Park, Barneyhill and Milverton, none of the samples reached a high standard. One might have expected that, in these conditions, the effect of manuring in improving quality would have been very pronounced; actually it is rather small, as shown in Table 4.

TABLE 3.—VALUE PER QUARTER OF 448 LB. AS ASSESSED BY THE VALUATION COMMITTEE.

	Rothamsted.	Cawwell.	Wellingore.	Barneyhill.	Milverton.	Dereham.	Woburn.	Orwell Park.	Walcott.
No manure	s. 36	s. 28	s. 36	s. 48	s. 45	s. 31	s. 27	s. 65	s. 30
Complete manure	31	30	36	48	—	31	27	65	30
No potash	31	30	36	48	48*	31	27	64	30
No phosphate	32	30	32	45	—	31	27	64	30
No nitrogen	31	30	40	53	55	31	27	60	30

* No nitrogen supplied.

TABLE 4.—EFFECT OF MANURING ON VALUATION AT EACH INDIVIDUAL CENTRE.

	Rothamsted.	Cawkwell.	Wellington.	Barneyhill.	Dereham.	Woburn.	Orwell Park.	Walcott.
Effect of complete manure	-5s.	+2s.	Nil	Nil	Nil	Nil	Nil	Nil
Effect of omitting—								
Potash ...	Nil	Nil	Nil	Nil	Nil	Nil	-1s.	Nil
Phosphate ...	+1s.	Nil	-4s.	-3s.	Nil	Nil	-1s.	Nil
Nitrogen ...	Nil	Nil	+4s.	+5s.	Nil	Nil	-5s.	Nil

Except at Milverton, and to an insignificant extent at Orwell Park, the addition of potash has had no effect on market value; the addition of Phosphate was in six cases without effect or almost so; it increased the value at Wellingore and Milverton and Barneyhill. The addition of nitrogen had little effect in lowering market value; in five cases there is no effect at all, in one (Orwell Park) there is a gain of 5s., and only in two is there the expected loss.

It is clear that the great factor determining value is regional (*i.e.*, soil, weather, etc.) and not manurial; in no case has it been possible by manuring to convert a bad sample into a good one. But if, instead of taking the figures as a whole, we confine our attention to the barleys valued at 36s. or more, ignoring the lower priced ones as being non-malting samples, we find that of the four surviving cases—Wellingore, Barneyhill, Milverton and Orwell Park—

Phosphatic manuring increased the value in all (though only slightly in one).

Nitrogenous manuring depressed the value in two, but increased it in one.

Potassic manuring had no effect in two, and increased it in two, though only slightly in one of these.

It will be interesting to see how far these results are obtained in a more normal season.

The influence of nitrogenous manure on quality is so important that an extended set of plots had been laid out at Rothamsted. Unfortunately, owing to heating in the stack, much of the barley was lost. Some of the completed results are given here:—

	Series 1.	Series 2.
No nitrogen	40s.	39s.
1 cwt. sulph. ammonia	40s.	39s.
2 cwt. sulph. ammonia	36s.	36s.

The harmful effect of additional nitrogen beyond the normal dressing is pronounced.

The Cross-cropped Plots.

At Eye and at Dunmow all samples were put at the same value, *viz.*, 30s. at the former and 42s. at the latter.

At Eyton the values were:—

No manure . . . . .	....	....	32s.
Complete manure . . . . .	....	....	32s.
No potash . . . . .	....	....	32s.
No phosphate . . . . .	....	....	40s.
No nitrogen . . . . .	....	....	40s.

Effect of Kiln-drying.

At two centres a plot was sown with kiln-dried barley, but no manure was given. At Barneyhill, East Lothian, an **increased** yield of 4 bushels of dressed grain was obtained, but a decreased market value of 3s. per quarter; while at Orwell Park a **decrease** of 2·5 bushels and of 8s. per quarter was obtained. As we do not understand the physiology of the process it is not possible to discuss these results. The general experience is that careful kiln-drying increases the yield without injuring the quality.

The Money Value to the Farmer of the Various Crops.

In arriving at the money value the head corn has been priced at the value put on it by the Valuation Sub-Committee while the tail corn has been priced at 26s. per quarter.

The cost of growing the crop without manure was £10 10s. per acre at Rothamsted, and £7 10s. at another centre on lighter soil. Possibly at the remaining centres the costs would come somewhere in between.

The cost of the manures was taken at the published quotations,* **plus** 1s. per cwt. for bagging, mixing, &c. The values thus obtained are:—

	February, 1922. per acre.
Complete manure (3 cwt. superphosphate, 1 cwt. sulph. ammonia, 1½ cwt. sulph. potash)	55s. 11d.
No potash	32s. 3d.
No phosphate	40s. 2d.
No nitrogen	39s. 5d.

The values of the increases in shillings per acre are given in Table 5.

With barley at 30s. to 36s. per quarter, it is quite obvious that manuring with a complete manure did not pay. Regard must be made to the fact that some of the phosphate and potash will remain unused for the succeeding crop; making this allowance two centres out of the eight, viz., Barneyhill and Orwell Park, have probably profited by the manuring. Incomplete manures are cheaper, and had we known beforehand what could be safely omitted, a handsome profit could have been made at Orwell Park and Eyton and a more modest one at Eye. At Wellingore and Barneyhill the dressing without potash has rather more than paid for itself.

Too much importance should not be attached to these figures. The unfavourable character of the season has already been recorded. The object of the experiment is not to find the most economical dressing

* These however, are for 4-ton lots and cash.

TABLE 5.—MONEY VALUES OF THE VARIOUS CROPS.

	Rothamsted.	Cawkingwell.	Wellington.	Barneyhill.	Milverton.	Dereham.	Woburn.	Orwell Park.	Walcott.	Eyton.	Dunmow.	Eye.
Value of unmanured— Per quarter	£. 36	£. 28	£. 36	£. 48	£. 45	£. 31	£. 27	£. 65	£. 30	£. 32	£. 42	£. 30
Per acre	127	94	167	471	146	147	131	132	233	149	274	196
Additional per acre for manuring—												
Complete manure	9	32	14	63	—	15	5	43	13	32	—6	20
No potash	—12	1	34	33	3*	21	—5	65	10	38	—17	17
No phosphate	16	24	—1	7	—	—4	—10	91	14	79	—6	39
No nitrogen	—7	—7	24	29	10	—28	1	5	12	98	—30	50

* No nitrogen supplied; cost of fertiliser 15s. 9d.
The figures underlined are those in which a profit is shown.

for barley, but the principles on which the most economical dressing may be designed. The experiments aim at discovering the effect of fertilisers on the yield and quality of barley under different conditions of soil and season. When this has been done the finding of the most economical dressing for a particular farm becomes simply a question of applying the results. The experiments show quite clearly, however, that when prices of produce are low and the season is unfavourable, the farmer is unlikely to gain by using a manure made up according to a general prescription ; his only hope is to use a special manure adapted to his farm.

The Effect of Manuring on Nitrogen Content of Grain.

The percentages of nitrogen are given in Table 6. They vary in the different samples from 1·36 to 2·33 per cent., but the variations from plot to plot on the same farm are much smaller than the variations from farm to farm, as happened also in the case of value. The highest percentages, averages and singles, were obtained on the black, heavy soil of Eye, Peterborough (2·13), closely approached, however, by the sample from the good red soil of Eyton, Shropshire (1·92). The lowest percentage was obtained at Barneyhill (1·44). The data are at present insufficient to allow of discussion.

On the individual farms the variations are much smaller. Nitrogenous manuring almost always increases the nitrogen in the grain (in nine cases out of eleven, though of these two are doubtful) ; potassic manuring lowers it in five cases out of twelve, and phosphatic manuring in three cases ; in all instances, however, the changes associated with manuring are slight.

Relationship between Nitrogen Content and Valuation of Grain.

There is a general connection between nitrogen content and valuation especially when averages of different farms are compared (Table 6).

The figures as a whole show that the reduction in value usually associated with increasing nitrogen content of grain is less when comparing barleys from the same farm than when comparing barleys from different farms ; in these particular cases an increase of 0·1 per cent. of nitrogen content of grain above the mean value results in a reduction of 2s. 9d. per quarter when comparing barleys from different farms, but of only 10d. per quarter when comparing barleys from different plots on the same farm. The difference becomes much less, however, if

Table 6.—Nitrogen per cent. and Price.

Treatment.	Rothamsted.		Cawkwell.		Wellingore.		Barneyhill.		Milverton.		Dereham.	
	Per cent. Nitrogen.	Price.	Per cent. Nitrogen.	Price.	Per cent. Nitrogen.	Price.	Per cent. Nitrogen.	Price.	Per cent. Nitrogen.	Price.	Per cent. Nitrogen.	Price.
No manure....	1.60	36	1.56	28	1.76	36	1.36	48	1.53	45	1.62	31
Complete manure ...	1.64	31	1.57	30	1.80	36	1.47	48	—	—	1.67	31
No potash ...	1.69	31	1.49	30	1.78	36	1.50	48	1.64	48*	1.62	31
No phosphate ...	1.63	32	1.49	30	1.89	32	1.47	45	—	—	1.69	31
No nitrogen ...	1.58	31	1.50	30	1.72	40	1.38	53	1.48	55	1.66	31

	Woburn.		Orwell Park.		Walcott.		Eyton.		Dunmow.		Eye.	
	Per cent. Nitrogen.	Price.	Per cent. Nitrogen.	Price.	Per cent. Nitrogen.	Price.	Per cent. Nitrogen.	Price.	Per cent. Nitrogen.	Price.	Per cent. Nitrogen.	Price.
No manure....	1.78	27	1.43	65	1.70	30	1.85	32	1.75	42	2.11	30
Complete manure ...	2.09	27	1.52	65	1.88	30	1.90	32	1.75	42	2.17	30
No potash ...	2.10	27	1.53	64	1.79	30	2.10	32	1.85	42	2.13	30
No phosphate ...	1.91	27	1.55	64	1.88	30	1.87	40	1.75	42	2.23	30
No nitrogen ...	1.87	27	1.51	60	1.72	30	1.90	40	1.78	42	2.02	30

* Superphosphate only given in this case.

one eliminates all the low-priced barleys which, owing to their unsuitability for malting, are put at a uniform price level regardless of nitrogen content; in this case the reduction in price for barleys of different farms for each 0.1 per cent. of nitrogen is still 2s. 9d. per quarter, but it becomes 2s. instead of 10d. when comparing barleys on the same farm, a difference on which stress can not at present be laid.

It is probable that the form in which the nitrogen occurs, as well as its amount, is of importance.

						Price per quarter.	Nitrogen.	
Orwell Park	....	..	....	....	....	62s. 6d.	1.51	*
Barneyhill	....	..	....	....	....	48s. 6d.	1.44	*
Milverton	....	....	....	....	....	49s.	1.55	*
Dunmow ....	....	....	....	....	....	42s.	1.77	
Cawkwell	....	..	....	....	....	30s.	1.52	
Wellingore	....	....	....	....	....	36s.	1.79	†
Eyton	....	..	....	....	....	35s.	1.92	†
Dereham	....	..	....	....	....	31s.	1.65	†
Walcott	..	..	....	....	....	30s.	1.79	†
Eye	..	....	....	....	....	30s.	2.13	†

* High price, low nitrogen.

† Low price, high nitrogen.

STATISTICAL NOTE ON THE DATA RELATING TO NITROGEN CONTENT AND VALUATION.

By R. A. FISHER, M.A.

Head of Statistical Laboratory, Rothamsted Experimental Station.

The influence of nitrogen content upon the valuation is most directly measured by the average fall in price for any additional increment of, say, 0.1 per cent. in nitrogen content. Thus, if a very large number of barleys were valued and analysed, and of them we chose 1,000 with nitrogen content 1.4—1.5 per cent., and so on, then we might expect the average price per bushel of each set of a thousand samples to be less than that preceding it, and greater than that following, by a fixed amount of money. This amount clearly measures the monetary importance of nitrogen content.

The accuracy with which the constant monetary difference would be determined by such an experiment as the above would depend on the number of samples. If, for instance, only 10 samples were available of each nitrogen content, we should expect the average prices to form an irregular, but generally descending series. To estimate the average falling off in prices with any accuracy it would be necessary to compare price with nitrogen content over the whole range of nitrogen content

available. In modern statistical practice such averaging may be accomplished even when the nitrogen contents are not arranged in steps at regular intervals, and the average falling off in prices may be directly calculated, under the name of the "regression of price on nitrogen content."

Taking first the mean price and mean nitrogen content at each of the 11 centres, we may see how much influence nitrogen content has on price with barley from different districts. It appears from this data that the price falls off 27s. 9d. per quarter for 1 per cent. of nitrogen, or 2s. 9d. for 0.1 per cent. Such a calculation would have to be based on much more extensive data, if it were to be applied generally; but for our present purpose when we wish to compare it with the corresponding figure for variations between different plots at the same station, this is the figure required, although it is based on only 10 independent comparisons.

At each centre five comparable plots were grown, giving four independent comparisons for each centre, or 44 in all; a weighted mean value for the regression may thence be calculated, and comes out in this case to be 8s. 4d. for 1 per cent., or 10d. per bushel for 0.1 per cent. This is materially less than the value obtained by comparing barley from different districts. Statistically the difference is, I think, not due to chance; it is a matter for further investigation to what extent the conditions under which the valuation was carried out may have contributed to produce it.

One factor which may be clearly distinguished is that if the barley as a whole does not come up to malting standard, its value will not be depressed by additional nitrogen. If in the above calculation four stations in which this is the case are omitted, the comparison between stations gives an almost unaltered value (27s. 1d.), but the comparison within the seven malting barley stations gives 19s. 8d. in place of 8s. 4d.

The fact would seem to be that whereas to the maltster barley is worth some 2s. 9d. per bushel for each 0.1 per cent. nitrogen below the mean value, the farmer must also take into consideration the fact that his barley may not be bought for malting at all, and therefore his expected loss in price for increased nitrogen is on the average materially less than the loss of value to the maltster.

R. A. FISHER.

Summary.

This being the first season's work it is not possible to draw any conclusions from the experiments. The observations are reported sufficiently fully to allow comparisons in future years. The following summary is intended simply to facilitate the use of the present report.

1.—At most centres a good seed-bed could be prepared and the barley went in well. Except at Barneyhill a drought came on through May and June which checked plant growth. A cold wet summer was followed by thoroughly bad harvest weather. The yields were not severely affected, but the quality was usually very much depressed.

2.—The complete artificial manure gave an increased yield at practically all centres, but only in two cases was the valuation affected, once favourably and once adversely.

3.—Nitrogenous manure (sulphate of ammonia) produced its usual effect of increasing the yield by about 5 bushels for 1 cwt. sulphate of ammonia, excepting only in two or three readily explained cases.

4.—Phosphates were ineffective at several centres on heavy soils where they would normally be expected to act. On the very light sand they apparently depressed the crop. We believe this to be a true effect attributable to the well-known action of phosphates in accelerating maturation. If this is confirmed by later observations it will necessitate a modification in the manurial treatment of barley on light land.

Potassic fertilisers in several cases had a marked effect in increasing yield.

5.—The valuations of the samples were much more influenced by the soil and season than by manuring. The data are insufficient to allow of detailed discussion of the reasons for the great differences, but in no case did the manuring raise or depress the sample far out of its general level of value.

When the samples were taken as a whole no clear connection between manuring and valuation was apparent, but when attention was confined to those priced above 35s. per quarter, and therefore of fair to good malting value, it appeared that nitrogenous manuring tended to lower the valuation and phosphates to raise it; but potassic fertilisers had no consistent effect.

6.—The percentages of nitrogen in the different samples of grain were, like the valuation, much more influenced by soil and season than by manuring. Nitrogenous manures raised the nitrogen content of the grain and potassic manures tended to depress it; phosphates were less effective.

7.—The relationship between nitrogen content and valuation was clearly marked when the averages for one farm were compared with those for another, an additional 0·1 per cent. of nitrogen depressing the valuation on an average 2s. 9d. per quarter. But the relationship was not so well marked when the individual plots on one and the same farm were compared. It became clearer, however, if attention was confined, as before, to barleys priced above 35s. per quarter. On these farms each additional 0·1 per cent. nitrogen on an average lowered the value of the barley by 2s. per quarter.

APPENDIX II.—Farmers and Sir John Russell's Reports on Growing Crops.

PLOTS.

- | | |
|--------------------------|------------------|
| 1.—No Manure. | 3.—No Potash. |
| 2.—Complete artificials. | 4.—No Phosphate. |
| 5.—No Nitrogen. | |

1.—Rothamsted—

Plot.

May 22nd.—1.—Growth stunted, blades paler, narrower, less tillering.

2.—Growth good. Not so green as 4. Normally tillered.

3.—Growth less good than 4.

4.—Growth less than 2. Colour good.

5.—Colour paler than 3. Growth moderate.

June 5th.—1.—Growth moderate, rows even, very little tiller. Colour lighter but still good.

2.—Growth fair, inclined to be patchy. Colour good, on dark side.

3.—Growth moderate, but less spreading than 2 and 4. Colour lighter.

4.—Growth good but less than 2, irregular. Colour good, gappy in parts.

5.—Growth moderate, rows even, little tillering. Colour fair.

June 19th.—1.—Growth poor. Colour yellower. Crop thinner than any other, but regular; dying off normal.

APPENDIX I.—List of Centres with Details.

[To face p. 645.]

Centre.		Particulars of soil, field, and size of plot.	Previous crop and manuring.	Rate of seeding and date of sowing Barley, 1922.	Date of applying manures.	Date of cutting.	Approximate date of threshing.	Season.	
								Early.	Late.
EASTERN SIDE.									
<i>Herts</i> — Rothenastad Experimental Station.	Experi-	Soil: Clay with flints; heavy strong soil overlying chalk. 3½-acre plots.	Wheat: 1 cwt. superphosphate and 1 cwt. sulphate of ammonia.	March 30: 10 pecks per acre	March 24	Sept. 12	Dec. 21	Very dry	Wet, cold and sunless.
<i>Beds</i> — Woburn Experimental Farm.	Experi-	Sandy loam; junction of lower greensand and Oxford clay; deep, low-lying and apt to be wet. 4-acre plots.	Mangolds — F.Y.M. — Small crop only.	Apr. 19: 10 pecks per acre	Minerals, Apr. 19; Sulphate of Ammonia, June 30.	Sept. 9	Dec. 21	Sowing delayed till early May; cold and wet; later hot and dry.	Excessive rain in June, followed by cold, wet weather.
<i>Essex</i> — Dunmow	Wm. Haaler, Esq., Barnett, Esq., Barnett, Esq. (G. Bellfield, Esq.)	Medium to heavy loam; very stony; 2-acre plots.	Potatoes (§ of Plot 1). Mangolds on rest of Plot 1; on 2, 3 and 4, Kohlrabi on rest; 1 ton of 4. F.Y.M.: 2 cwt. kainit; 1 cwt. sulphate of ammonia.	Apr. 23	Apr. 23	—	—	Hot sun, only little rain.	—
<i>Suffolk</i> — Oswell Park (Howes Farm, Martineham).	Esq. G. G. Fretyman, Esq. (Howes Farm, Martineham).	Light sand on sand. Home Field, half-acre plots.	White turnips, very poor crop; lightly run over by sheep.	Apr. 15: 2 bush, per acre	Apr. 15	Aug. 30	Dec. 6	Very dry	—
<i>North</i> — Dereham	Esq. H. Hill, Esq., Hall Esq., Farm, Gressendale.	Mixed soil overlying chalk (Lower Field), one-acre plots.	Oats after hay. Oats had 10 loads F.Y.M.; 1 cwt. sulphate of ammonia.	Apr. 7: 12 pecks per acre	Apr. 7	Aug. 28	Dec. 6	Very dry	—
<i>Peterborough</i> — Eggs M., Eggs S., Northholme.	Esq. M., Esq., Northholme.	Edge of fen. Black soil on clay; three-quarter acre plots.	White mustard and F.Y.M. on Plot 1 and 1 of 2. Rest of 2 and 3 had F.Y.M., 4 and 5 had nothing.	Apr. 6: 12 pecks per acre	Apr. 6	Sept. 4	Jan. 15	Hot, dry	Wet, cold.
<i>Lincoln</i> — Wellington	Esq. G. H. Neville, Esq.	Oolite limestone loam; about 8 inches of soil. Plots 3·3 acres each.	Barley (1921) after seeds eaten by sheep, 1920.	March 22: 3 bush, per acre	Apr. 11	Sept. 15	Nov. 14	0·5 in. rain only in May and June, barley suffering. Very dry.	*
Walscott	Esq. C. Bembridge, Esq.	High Dyke Field. Plots, two acres each.	Barley (1921) after Barley, 1920, and Potatoes, 1919. Some artificial, but no F.Y.M. in 1921.	Apr. 3 and 4: 8 pecks per acre	Apr. 3 and 4	Sept.	Dec. 6	Particularly dry.	—
Cawwell	Esq. Scamblesby, Esq.	Chalk Wolds. Red, rather heavy loam overlying chalk, 6 inches to 12 inches down. Flint Walk Field. Two-acre plots.	Mangold-stem kale which received 3 cwt. kainit; 2 cwt. bone meal; 2 cwt. superphosphate, and was fed off with sheep with 3½ lb. cake daily.	Apr. 24	Apr. 24	Sept. 18	—	—	—
<i>East Lothian</i> — Barneyhill (Sir Harry Hope).	Esq. A. E. Davy, Esq.	Red loam. One-acre plots. Hope Field.	Potatoes, 18 tons F.Y.M. in autumn and 9 cwt. complete manure. 18 tons to 2 cwt. sulphate of potash.	Apr. 13: 2½ bush, per acre	Apr. 13	Sept. 4	Oct. 20	No rain till end of June.	—
WESTERN SIDE.									
<i>Shropshire</i> — Eytton-on-Severn	Esq. E. Craig Tanner, Esq.	Triass. Red medium loam inclined to be gravelly. One acre plots. Himmer's Field.	Plots 1 and 2 vetches; 3, 4 and 5 common turnips. All area lightly run over by sheep.	Apr. 10: 9 pecks per acre	Apr. 15	—	—	Dry.	—
<i>Somerset</i> — Milverton	Esq. W. H. Edwards, Esq.	Triass. Red sandy loam. Plots 2, 543 sq. yds. (No. 1), 2,531 sq. yds. (No. 2), 2,531 sq. yds. (No. 3) (H. Springlands Field).	Cabbages. 20 loads rotted manure.	March 28	May 23	Aug. 31	Dec. 2	No rain, hot, dry till end of June. Rain, no sun later.	—
<i>Wiltshire</i> — Warminster	Esq. E. S. Beaven, Esq.	—	—	—	—	—	—	—	—

* 5 inches rain in July. Damp, sunless August.

Plot.

- June 19th.*—2.—Growth fair. Colour good, patchy glaucous, leaf tips dying. Tillering not progressing.
 3.—Growth only medium. Colour irregular, patchy. Yellower than 2 and 4.
 4.—Growth fair, colour good, gappy. Less dying off than 2.
 5.—Growth medium. Colour very irregular, gappy in parts. Leaves dying.

- July 5th.*—1.—Growth poor. Colour lighter, even, very few ears.
 2.—Colour good, inclined to glaucous. Growth good though blades narrow. Ears about $2\frac{1}{2}$ inches. regular, awns taking reddish brown colour.
 3.—Thin growth, less than 4. Colour good, patchy. Much less ear than 2 and 4.
 4.—Gappy, growth less than 2. Colour good, inclined to glaucous. Ears less developed than 2, but with awns turning red.
 5.—Growth good, even, good leaf and tiller. Ears well developed but not so red in awns as 2, 3 and 4, less glaucous. Few ears.

- July 29th.*—1.—Fair, tail as 5, but thinner; light colour, medium ear, regular in growth.
 2.—Growth good, even. Ears about $2\frac{1}{2}$ inches, all out of sheath, leaves good green colour.
 3.—Plot thin, growth much less than 4. Ears short and less well filled than 4.
 4.—Growth less than 2, glaucous appearance. Ear full out. Less blade.
 5.—Better than 3.

2. Woburn—These plots were under the direct supervision of Dr. J. A. Voelcker, who has kindly interested himself very much in the investigation. He reports that at no time were any marked differences observed, and points to the high yield of the unmanured plot as showing that the land was in too good condition to bring out the differences expected from the manures.

3. Dunmow, Essex—

June 23rd.—Only little difference. *No manure*, very good but much dark green colour. *Complete manure*, more uniform. *No nitrogen*, lighter colour and less growth than rest.

August 15th.—Plot 1.—*No manure.* Some green barley and many florets fail to form seed. Plot 2.—*Complete manure.* Best of all, but effects did not show for about two months owing to drought. Bottom of heads better filled than on 3 and 4. Plot 3.—*No potash.* A number of heads not completely filled at bottom. Plot 4.—*No phosphate.* About equal to 3. Plot 5.—*No nitrogen.* Began to change colour about August 8th being the first plot to do so. Awns beginning to fall off before the barley is ripe. Less growth than on other plots.

4. Orwell Park—

June 22nd.—All looking very poor, yellow at bottom. Very dry. Possibly No. 2 (*complete manure*) best ; *unmanured* poorest. Looks as if crop will not be worth harvesting.

August 23rd.—All crops poor, but effect of manure is marked. Straw short. Plots 2, 3 and 4 fair ; 1 and 5 very poor, both in yield and quality. All plots ripening together.

After threshing.—Yield considerably above that of other barley on same soil (average this season is 20 bushels) and quality better.

5. Dereham—

June 21st.—Season very dry. Plot No. 2 (complete manured) best ; No. 1 (unmanured) poorest.

August 18th.—Plot No. 2 best, ears better and more regular. No. 1 poorest ; Nos. 3, 4 and 5 not much better than 1. All standing up well, and better than Irish Archer which is laid. Weather bad for harvest.

6. Eye—

June 24th.—Plot 1.—Lighter colour than 2. Plot 2.—Distinctly better, but so was mustard last year. Plot 3.—Lighter colour than 2. Plot 4.—Thicker than rest and going down in places. Plot 5.—Less growth, but nice even crop.

August 21st.—All plots somewhat down. Plot 1.—*Unmanured* : Less ripe than rest. Plot 2.—*Complete manure* : Variable. Plot 3.—*No potash* : Heads smaller, not so well filled as 2, grain apparently coarser. Plot 4.—*No phosphate* : Less coarse, but more green stems than on 3. Plot 5.—*No nitrogen* : Best of all.

At threshing, local valuer put samples in the following order :—Plot 3 (no potash) : best ; Plots 4, 5, 2 and 1 (unmanured) : worst.

7. Wellingore—

June 4th.—All looking well and much alike. No potash plot has darker colour than the rest.

June 21st.—No great difference; complete manure and no potash plots somewhat the best; unmanured looks the poorest. Plots receiving sulphate of ammonia show better colour.

August 18th.—Crops look well for yield; good plump grain but poor colour. *No manure*, smallest heads, look like ripening first. *Complete artificials*, apparently 2 quarters more than unmanured. *No nitrogen*, fewer small and green heads than the rest.

8. Walcott—

June 5th.—Very even set of plots. No. 1, no manure, least good. Rather patchy in appearance. No. 2, best. No. 3, no potash, less even than complete manure, with some lighter patches. No. 5, no nitrogen, less growth than 4.

August 17th.—The wet weather has knocked the corn about terribly. Plot 1, certainly the worst; 2 and 4 probably the best.

9. Cawkwell—

June 6th.—Plot 2, *complete manure*, best. Plot 3, *no potash*, not so good, soil may be thinner. Plot 5, *no nitrogen*, not so green as rest.

June 21st.—Plot 2, still the best, but Plots 3, 4 and 5 have much improved.

August 22nd.—Plots 2 and 5 look the best, the latter being the most uniform.

10. Barneyhill, East Lothian—

June 21st.—*Complete manure*, looks like being too strong and may lodge if much rain comes.

July 3rd.—*Complete manure*, best. Crop darker in colour than untreated plot, standing up well and heading out well. *No potash*, less forward, less growth and vigour. Heads only just coming out. *No phosphate*, much more vigorous. *No nitrogen*, lighter in colour. Seeds sown in barley are looking well.

September 7th.—*Complete manure*, best crop, so throughout. Down in a few places, ripening well. *No potash*, weaker in straw, heads do not stand up so well (yet preceding crop had $1\frac{1}{2}$ to 2 cwt. sulphate of potash).

No phosphate, bigger than "no potash" though less ripe; not standing up so well as complete manure. *No nitrogen*, ripest, stands up best; shorter and finer in straw than others.

Kiln-dried Barley.—Quite good crop, ripening well.

The yields this year are the heaviest for thirty years. The late frosts gave a good tilth without much work. The crops never got a check from drought—which is unusual here, as very often it is too dry before the shooting out stage.

11. Eyton—

June 3rd.—No manurial effects visible. Plots 2 and 5 (complete and no nitrogen), looking rather patchy; 3 and 4 more even.

August 19th.—*Unmanured*. Short and weak in straw, smallest crop. *Complete manure*, heaviest crop, long in straw, but weak and inclined to go down. Plots 3, 4 and 5 stand up well, good and even; plot 3 may be slightly the heavier.

NOTE.—Owing to late sowing the harvest was late and the average value (32s. to 40s.) below that for the barley on the rest of the farm (53s.).

12. Milverton—

June 22nd.—Seed went in well but there has been practically no rain since. No visible differences between the plots.

July 30th.—Crops not large, but have picked up since rain. *Super phosphate + potash*, best. *No manure*, poorest and least ripe.

August 21st.—Very little difference. All plots are standing well. Super. and potash plot has slightly best developed grain.

APPENDIX III — Crop Results and Valuations.

Centre.	Treatment	Dressed grain		Tail corn.		Value per acre.		
		Bush per acre *	at per qr	lb per acre.	Head corn	Tail at 26s.	Total.	
Rothamsted	Nil	25 8	s 36	184	e. 116	e. 11	e. 127	
	Complete manure	32 6	31	163	127	9	136	
	Less Potash	27 0	31	175	105	10	115	
	Less Phosphate	33 0	32	191	132	11	143	
	Less Nitrogen	28 2	31	188	109	11	120	
	Complete with Potassium Chloride	31 0	34	206	132	12	144	
Woburn	Complete with Ammonium Chloride	32 5	36	169	146	10	156	
	Nil	37 9	27	54	128	3	131	
	Complete manure	39 0	27	65	132	4	136	
	Less Potash	36 1	27	62	122	4	126	
	Less Phosphate	34 9	27	50	118	3	121	
	Less Nitrogen	27 9	27	66	128	4	132	
Dunmow, Essex (Mr Hasler)	Sheep fed only	35 1	32	69	140	4	144	
	Sheep fed, plus Superphosphate	31 8	32	99	127	6	133	
	Nil	51 0	42	98	268	6	274	
	Complete manure	49 5	42	137	260	8	268	
	Less Potash	47 0	42	179	247	10	257	
	Less Phosphate	49 0	42	193	257	11	268	
	Less Nitrogen	45 0	42	133	236	8	244	

* Bushels given are of 56 lbs

Centre.	Treatment.	Dressed grain.		Tail corn.		Value per acre.		
		Bush. per acre.†	at per qr	lb. per acre.	Head corn.	Tail at 26c.	Total.	
Orwell Park (Mr. Pretymann).	Nil	16 2	s. 65	Amount only small.	s. 132	s. —	s. 132	
	Complete manure	21·6	65		175	—	175	
	Less Potash	24 6	64		197*	—	197*	
	Less Phosphate	27 9	64		223*	—	223*	
	Less Nitrogen	18 2	60		137	—	137	
	Kiln-dried	13 7	57		98	—	98	
Dereham (Mr. Hull).	Nil	36·7	31	84	142	5	147	
	Complete manure	41·0	31	56	159	3	162	
	Less Potash	42·0	31	84	163	5	168	
	Less Phosphate	36·0	31	56	140	3	143	
	Less Nitrogen	30 0	31	56	116	3	119	
Eye, Peterboro' (Mr. Eger).	Nil	39·5	30	828	148	48	196	
	Complete manure	43·5	30	919	163	53	216	
	Less Potash	44·1	30	831	165	48	213	
	Less Phosphate	50·9	30	751	191	44	235	
	Less Nitrogen	59·1	30	407	222	24	246*	
Wellington, Lincoln. (Mr. Neville).	Nil	36 1	36	69	163	4	167	
	Complete manure	39·0	36	86	176	5	181	
	Less Potash	43·5	36	80	196	5	201	
	Less Phosphate	40 5	32	73	162	4	166	
	Less Nitrogen	37 3	40	74	187	4	191	

Walcott, Linca. (Mr. Bembridge).	Nil	...	...	...	...	...	30	214	19	233
	Complete manure	...	...	...	56.9	...	30	226	20	246
	Less Potash	...	...	...	60.3	...	30	220	23	243
	Less Phosphate	...	...	...	61.3	...	30	230	17	247
	Less Nitrogen	...	...	...	60.8	...	30	228	17	245
Cawwell, Louth (Mr. Davy).	Nil	...	...	...	25.2	...	28	88	6	94
	Complete manure	...	...	...	30.9	...	30	116	10	126
	Less Potash	...	...	...	22.6	...	30	168	10	95
	Less Phosphate	...	...	...	28.8	...	30	108	10	118
	Less Nitrogen	...	...	...	23.1	...	30	87	6	93
Barneyhill, East Lothian. (Sir Harry Hope).	Nil	...	...	...	78.5	...	48	471	—	471
	Complete	...	...	...	89.0	...	48	534*	—	534*
	Less Potash	...	...	...	84.0	...	48	504*	—	504*
	Less Phosphate	...	...	...	85.0	...	45	478	—	478
	Less Nitrogen	...	...	...	75.5	...	53	500	—	500
Eyton-on-Severn (Mr. Craig Tanner).	Kiln-dried	...	...	...	82.5	...	45	464	—	464
	Nil	...	...	...	36.0	...	32	144	5	149
	Complete	...	...	...	28.0	...	32	112	5	117
	Less Potash	...	...	...	45.2	...	32	181	6	187*
	Less Phosphate	...	...	...	44.5	...	40	222	6	228*
Milverton, Somerset (Mr. Edwards).	Less Nitrogen	...	...	...	48.0	...	40	240	7	247*
	Nil	...	...	...	26.0	...	45	146	—	146
	Complete	...	...	...	23.3	...	55	160	—	160
	Superphosphate only	...	...	...	27.2	...	48	163*	—	163*

† Bushels given are of 56 lbs.

* Have paid for the manures.

APPENDIX IV.—Weather Conditions, 1922.

Rothamsted—

Date.	Rainfall, inches.	Average Rainfall, 1888-1916.	Difference from Average.	Hours of Sunshine.
January	3.148	2.15	+ .998	53.7
February ...	2.507	2.02	+ .487	104.9
March	2.285	2.41	— .125	113.5
April	3.520	1.69	+1.83	149.8
May	1.579	1.99	— .411	280.2
June	1.038	2.53	—1.492	228.8
July	4.605	2.41	+2.195	149.5
August ...	2.930	2.83	+ .100	127.3
September ...	2.882	1.87	+1.012	102.6
October	0.764	3.23	—2.466	140.0
November ...	1.433	2.64	—1.207	56.8
December...	3.091	3.05	+ .041	55.5

Average for year, 28.82 inches of rain.

January.—First week fine, remainder variable ; better than usual.

February.—Mild ; wetter than usual.

March.—Cold ; normal rainfall.

April.—Soil dry, favourable for seeding. Barley went in well.

May.—Fine and hot. Dry, except for occasional heavy showers (0.7 inches on the 25th).

June.—Dry, dull usually ; hot till last week, when heavy rain.

July.—Very wet, cold and sunless.

August.—Many wet days, but total rainfall equal to average. Cold and sunless. Harvest weather bad, cutting hindered, corn ripened only slowly, but there was much growing in the shocks.

September.—Wetter than average ; cold and sunless.

Woburn.—

Notes on Season.—The absence of drying winds, with April, 1922, a very wet month, delayed spring cultivation and retarded the sowing of spring corn crops.

The early part of May was also cold and wet, though the second half was hot and dry, this continuing throughout June until the third week of that month, when excessive rainfall and spells of cold, wet weather, along with absence of sunshine, characterised July.

August and September were also cold and wet, and everything was against the proper ripening and harvesting of the crops, which were got in with difficulty.

Orwell Park—

The total rainfall during the year in this neighbourhood was $23\frac{1}{2}$ inches, but up to August 25th, the total was only 15·10, of which 4·17 fell in January. The farm did not suffer therefore from the excessive rain experienced in many parts of the country, and, above all, it missed the particularly heavy fall at harvest time which did so much damage to grain in the stook, even in places not 30 miles away. In fact, the season was actually too dry and with a little more moisture the yields would probably have been heavier without injury to the quality.

THE INSTITUTE OF BREWING RESEARCH SCHEME.

REPORT ON THE EXPERIMENTS ON THE INFLUENCE
OF SOIL, SEASON, AND MANURING ON THE QUALITY
AND GROWTH OF BARLEY AS INDICATED BY THE
MALTS MADE THEREFROM.

By H. M. LANCASTER.

the pound of brewers' extract has been fixed on the basis of the average prices of malt made from 1922 barleys as follows:—

For No. 1 malts	...	10d.	or about 80s. per Qr.
For No. 2 malts	...	9d.	" 72s. "
For No. 3 malts	...	8d.	" 64s. "
For No. 4 malts	...	7d.	" 55s. "
For No. 5 malts	...	6d.	" 47s. "

The No. 5 group need not be considered as these barleys would not have been bought for malting, at any rate for the use of brewers. Any barley which worked out to a value of below 30s. as malting material has been classed as grinding barley.

Brewers' Extract.

Brewers' Extract has been determined by the Committee method (this Journ., 1922, 28, 775), but for purposes of comparison it has been calculated on *dry* malt.

Malting Loss.

Malting loss has been calculated on dry matter, the arbitrary figure of 17·4 per cent. having been taken as the moisture content of all the barleys. This figure is probably too low for the season, but it affords a basis of comparison and gives a round figure of 370 lb. of dry barley for each quarter of raw barley.

The figure obtained in column 5, therefore, represents the pounds of brewers' extract actually obtained from 448 lb. of raw barley, estimating the moisture content of each barley as 17·4 per cent. Column 7 shows the value of the malt extract obtained from 448 lb. raw barley subject to the *quality* of the malt, deducting 25s. per quarter for freight, malting costs and maltsters' profit.

Malting Method.

Three hundred grammes of dried barley were weighed and tied up in a cylindrical bag of gauze, and steeped, floored and kilned with steepes of 100 quarters each.

It was not found necessary to open the bags from the time they were steeped until the time they were taken off the kiln, but each day they were taken out of the floor, and loosened. The flooring temperature varied from 56° to about 66° F., except in the series C. 30 (see Appendix, page 11), when it rose to nearly 70° F. on two days. The flooring

period was nine days, which proved sufficient under the experimental conditions adopted.

The barleys were divided into two groups, and these were steeped in alternate weeks so that each series should have as nearly as possible similar weather conditions.

Four maltings were carried out of each barley, and the malting loss on each calculated. The average of the four being taken as the M/L of the barley.

It is found that the bag system of malting gives very fairly uniform results as each bag of each series is subject to almost exactly the same conditions, but, as compared with the piece of malt in which they are malted, the loss is generally rather higher.

All these experimental maltings were carried out in floors of brewing Californian barley, and a control bag containing 300 grms. of the same barley as the piece was used in each case as a control. The malting loss, therefore, has been corrected in each case according to the difference between the control and the piece—for instance, in steep 1 (see Appendix, page 16), the piece showed a malting loss of 7.3 per cent., and the control a malting loss of 8.1 per cent., so all the results of malting loss were corrected. In the case of No. 1, in which the malting loss was 7.9, the correction was $8.1 : 7.3 :: 7.9 : X$ ($X = 7.1$), and so on.

With regard to the brewers' extract, the results of the four experimental maltings of each barley were thoroughly screened and mixed in equal proportions and the mixture analysed. The extracts obtained have not been corrected, as the extracts from the controls were very nearly the same as those of the pieces.

Unfortunately, owing to the late harvest and the date at which the barleys were received, it was not possible to start malting them till March. Another year it is hoped to start the experiments in January, and finish by the end of March, which is a much better time of the year for experimental malting.

It must be remembered that in column 5, the extracts are calculated on 336 lb. of *dry* malt, and are therefore rather higher than those from commercial malt, but obviously Sir Harry Hope's barley, both without manure and with complete manure, would have yielded malts with 100 lb. of extract under working conditions of moisture content.

To illustrate briefly this similarity between uniform seed under divergent manurial conditions on the same farm, a table is appended showing the average brewers' extract and also the *highest* and *lowest*

extracts obtained from the quarter of raw barley (assuming a common moisture content of 17·4 per cent.) from each farm.

TABLE SHOWING AVERAGE, HIGHEST, AND LOWEST BREWERS' EXTRACTS, OBTAINED FROM 448 LB. RAW BARLEY. MOISTURE CALCULATED AT 17·4 PER CENT. AFTER MALTING ON THE STANDARD SYSTEM.

Centres.*	Av.	High.	Low.
Hope, Sir Harry	101·2	102·4	100·8
Pretymen, E. G., the Rt. Hon.	100·1	100·3	99·7
Edwards, W. H.	98·8	99·8	98·1
Davy, A. E.	97·9	98·6	97·4
Beaven, E. S.	96·1	96·0	94·7
Bembridge, C.	96·1	97·2	94·9
Neville, G. H.	95·9	97·3	95·0
Hasler, W.	95·8	97·0	94·1
Hill, W.	95·4	97·0	93·7
Craig Tanner, E.	95·4	97·0	93·6

* For particulars of centres, see this Journal, 1923, 625-626.

No comments have been made on the following figures as they represent the results of one season's work only. Those who study the figures carefully will doubtless form certain conclusions, but seasonal variations are so great in this country that the Committee feels that it is essential that further work should be carried on before deductions are drawn.

No.	Manurial Dressings.	(0) 1,000 Corn Weight Dry Barley. (Grams.)	(1) Nitrogen % of Dry Matter.	(2) Sub-Committee's Estimate of market value in Dec., 1922.	(3) M/L as % of Dry Matter.	(4) Brewers' Extract.		(6) Class of Malt.	(7) Value of 448 lbs. Raw Barley.	(8) Yield Bushels per Acre.	(9) Value per Acre (pence excluded).	No.
						per 336 lbs. Dry Malt.	per 448 lbs. Raw Barley.					
SIR HARRY HOPE, Barneyhill, East Lothian, N.B. (Soil : Trias.)												
1	<i>Kils dried seed</i>	47.4	1.36	45 0	8.3	99.2	100.2	1	s. d. 58 6	—	591 0	1
2	Unmanured	46.6	1.36	48 0	7.5	100.4	102.3	1	60 3	78.5	591 0	2
3	Complete manures	46.2	1.47	48 0	6.1	99.0	102.4	1	60 4	89.0	671 0	3
4	Without Potash	45.9	1.50	48 0	7.0	98.3	100.7	2	50 6	84.0	530 0	4
5	Without Phosphates	47.3	1.47	45 0	6.5	98.1	101.0	1	59 2	85.0	627 0	5
6	Without Nitrogen....	46.1	1.38	53 0	8.8	100.4	100.8	1	59 0	75.5	557 0	6
7	<i>From next field</i>	45.1	1.42	48 0	8.3	98.8	99.8	2	49 10	—	—	7
8	<i>1-6 bulked and dried</i>	44.9	1.50	55 0	8.9	98.5	98.8	1	57 4	—	—	8
W. HASLER, Dunmow, Essex. (Soil : Boulder Clay.)												
9	Unmanured	38.6	1.75	42 0	9.7	97.5	96.9	3	39 7	51.0	252 0	9
10	Complete manures	41.0	1.75	42 0	8.5	96.3	97.0	3	39 8	49.5	242 0	10
11	Without Potash	40.5	1.85	42 0	10.5	95.6	94.2	3	39 10	47.0	209 0	11
12	Without Phosphates	37.7	1.75	42 0	9.5	96.9	96.6	3	39 5	49.0	238 0	12
13	Without Nitrogen	40.3	1.77	42 0	7.5	94.1	95.5	4	36 8	45.0	172 0	13

No.	Manurial Dressings.	(0) 1,000 Corn Weight Dry Barley. (Grams.)	(1) Nitrogen % of Dry Matter.	(2) Sub-Committee's Estimate of market value in Dec., 1922.	(3) M/L as % of Dry Matter.	(4) Brewers' Extract.		(6) Class of Malt.	(7) Value of 448 lbs. Raw Barley.	(8) Yield Bushels per Acre.	(9) Value per Acre (pence excluded).	No.
						per 336 lbs. Dry Malt.	per 448 lbs. Raw Barley.					
A. E. DAVY, Louth, Lincs. (Wold). (Soil : Light Loam—Chalk.)												
14	Unmanured	36.8	1.56	28 0	8.9	97.7	98.0	3	s. 40 d. 4	25.2	s. 127 d. 14	14
15	Complete manures	38.3	1.57	30 0	8.5	96.8	97.5	3	40 0	30.9	154 0	15
16	Without Potash	36.6	1.49	30 0	9.2	97.9	97.9	3	40 3	22.6	114 0	16
17	Without Phosphates	41.7	1.49	30 0	9.8	98.1	97.4	3	39 11	28.8	144 0	17
18	Without Nitrogen	39.9	1.50	30 0	8.8	99.2	99.6	3	42 1	23.1	121 0	18
G. H. NEVILLE, Wellingore, Lincs. (Soil : Odite.)												
19	Unmanured	40.7	1.76	32 0	10.7	96.2	94.8	4	30 3	36.1	153 0	19
20	Complete manures	41.9	1.80	36 0	9.6	97.5	97.0	4	31 9	39.0	143 0	20
21	Without Potash	43.3	1.78	36 0	9.5	97.7	97.3	4	32 0	43.5	156 0	21
22	Without Phosphates	44.6	1.89	40 0	11.0	96.9	95.0	4	30 4	40.5	143 0	22
23	Without Nitrogen	41.9	1.72	36 0	11.5	98.3	95.8	4	30 10	37.3	157 0	23
E. CRAIG TANNER, Eytton-on-Severn, Salop. (Soil : Loam.)												
24	Unmanured	47.3	1.86	32 0	9.3	94.9	94.8	4	30 3	36.0	136 0	24
25	Complete manures	48.0	1.89	32 0	9.2	95.4	95.4	4	30 8	28.0	107 0	25
26	Without Potash	46.3	2.10	32 0	10.0	94.4	93.6	4	Grinding.	45.2	Grinding.	26
27	Without Phosphates	46.8	1.87	40 0	8.9	95.8	97.0	4	31 7	44.5	175 0	27
28	Without Nitrogen	48.2	1.90	40 0	9.2	96.0	96.0	4	31 0	48.0	186 0	28

W. H. EDWARDS, Milverton, Som.

(Soil : Trias.)

29	Unmanured	41.8	1.53	45 0	8.8	98.2	98.6	1	57 2	26.0	185 0	29
30	Without Potash and Nitrogen	43.3	1.64	48 0	9.3	98.2	98.1	2	48 3	27.2	164 0	30
31	Without Nitrogen	42.3	1.48	55 0	7.6	98.7	99.8	1	58 2	23.3	169 0	31

THE RT. HON. E. C. PRETYMAN, M.P., Nacton, Suffolk.

(Soil : Sand.)

32	Unmanured	42.7	1.43	65 0	8.1	99.9	101.1	1	59 3	16.2	121 0	32
33	Complete manures	43.8	1.53	65 0	8.8	99.9	100.3	1	58 7	21.6	158 0	33
34	Without Potash	43.6	1.53	64 0	8.8	99.4	99.8	1	58 2	24.6	179 0	34
35	Without Phosphates	43.3	1.55	64 0	9.5	100.0	99.7	1	58 1	27.9	202 0	35
36	Without Nitrogen	42.3	1.52	60 0	9.2	99.8	99.8	1	58 2	18.2	133 0	36
37	Kiln Dried	42.7	1.57	57 0	10.1	99.7	98.7	2	49 0	13.7	—	37

C. REMBRIDGE, Walcott, Lincs.

(Soil : Fen.)

38	Unmanured	36.2	1.70	30 0	8.7	95.3	95.8	4	30 11	56.9	220 0	38
39	Complete manures	34.2	1.88	30 0	8.0	94.6	95.8	4	30 11	60.3	227 0	39
40	Without Potash	33.8	1.79	30 0	8.8	94.5	94.9	5	Grinding.	58.7	243 0	40
41	Without Phosphates	35.7	1.88	30 0	6.6	94.5	97.2	4	31 8	61.3	243 0	41
42	Without Nitrogen	36.3	1.72	30 0	8.0	95.1	96.3	4	31 2	60.8	249 0	42

B. HILL, Dereham, Norfolk.

(Soil : Sand/Chalk.)

43	Unmanured	41.2	1.62	31 0	10.6	96.5	95.0	3	38 4	36.7	176 0	43
44	Complete manures	43.9	1.67	31 0	12.2	96.8	93.7	3	37 6	41.0	192 0	44
45	Without Potash	43.2	1.62	31 0	11.4	97.0	94.6	3	38 1	42.0	200 0	45
46	Without Phosphates	42.4	1.69	31 0	10.2	98.0	97.0	3	39 8	36.0	179 0	46
47	Without Nitrogen	41.9	1.66	31 0	10.2	97.7	96.7	3	39 6	30.0	148 0	47

ROTHAMSTED EXPERIMENTAL STATION, Harpenden, Herts.

[illegible]

OTHER ROTHAMSTED BARLEYS.

	AASI	% + S ₂ + Fe ₂ O ₃	39.4	1.76	45 0	8.6	97.9	98.5	3	40 8	20.1	102 0	105
Long Hoos Field	AAS2	Nil ...	41.2	1.57	36 0	9.6	97.7	97.3	3	40 2	32.0	160 0	106
	AAS3	{ P K, Na, Mg	42.8	1.73	32 0	11.7	96.7	94.0	5	Grinding	18.4	—	107
	AAS4	{ P K, Na, Mg, P	41.2	1.43	45 0	9.3	100.2	100.1	3	41 9	36.8	192 0	108
	7/1 No manure since 1872	...	42.5	1.32	45 0	8.7	98.8	99.1	3	41 1	17.7	91 0	109
	7/2 Farnyard manure	...	38.4	1.79	36 0	8.7	96.2	96.4	4	31 2	31.4	122 0	110
	6/1&2 no manure, coal ashes	...	37.2	1.26	43 6	9.2	100.0	100.0	3	41 9	7.2	38 0	111-2
Great Hoos Field	on 6/2												
	{ T.D. 1, P + 1 S/A ...	...	43.1	1.64	40 0	12.5	96.8	93.3	4	"	34.5	—	124
	{ T.D. 2, P + 2 S/A ...	...	42.7	1.63	36 0	12.8	95.1	91.3	5	"	31.2	—	125
	{ T.D. 3, P only ...	...	44.4	1.62	40 0	11.8	96.2	93.4	4	"	23.8	—	126
	{ T.D. 4, P + 1 M/A ...	...	47.5	1.69	40 0	11.7	96.9	94.2	4	"	27.7	—	127

No.	Manurial Dressings.	(0) 1,000 Corn Weight Dry Barley. (Grams.)	(1) Nitrogen % of Dry Matter.	(2) Sub-Com- mittee's Estimate of Market Value in Dec., 1922.	(3) M/L as % Dry Matter.	(4) Brewers' Extract.		(6) Class of Malt.	(7) Value of 448 lbs. Raw Barley.	(8) Yield Bushels per Acre.	(9) Value per Acre (pence excluded).	No.
						per 336 lbs. Dry Malt.	per 448 lbs. Raw Barley.					
NATIONAL INSTITUTE OF AGRICULTURAL BOTANY. Cambridge Station.												
131-6	Beaven's 1920	...	1.69	—	11.6	96.0	93.5	1*	...	...	...	131-6
132-7	Webb's B.	...	1.85	—	10.9	95.5	93.8	4	...	...	...	132-7
133-8	Golden Pheasant	...	1.94	—	11.9	95.6	92.8	2	...	...	...	133-8
135	Garton's 1917	...	1.90	—	11.6	93.9	91.4	3	...	...	...	135
140	Archer	...	1.82	—	11.7	94.0	91.5	5	...	...	...	140
Wallis Grange Station.												
151-6	Beaven's 1920	...	1.42	—	10.4	98.2	97.0	1	...	...	...	151-6
153-8	Golden Pheasant	...	1.67	—	11.0	96.9	95.0	2	...	...	...	153-8
155	Garton's 1917	...	1.57	—	12.0	93.7	90.9	3	...	...	...	155
160	Archer	...	1.56	—	12.4	95.5	92.2	4	...	...	...	160
Newport Station.												
171	Beaven's 1920	...	1.61	—	9.7	98.6	98.0	1	...	...	...	171
172	Webb's B.	...	1.68	—	11.4	96.2	93.9	4	...	...	...	172
173	Golden Pheasant	...	1.76	—	9.7	96.7	96.2	2	...	...	...	173
175	Garton's 1917	...	1.63	—	11.3	94.5	92.3	3	...	...	...	175
176	Archer	...	1.76	—	10.9	92.6	90.9	5	...	...	...	176

* NOTE.—These numbers do not refer to the class of malts. They represent the order in which the Valuation Committee placed the malts made from the N.I.A.B. barleys.

APPENDIX.

Being the figures for Malting Losses on the Barleys of the 1922 Crop received from the Experimental Plots (referred to in the Report). The figures in italics are the Malting Losses corrected by the Controls which are given at the foot of each column.

Index No.	BARLEY.				MALT.				MALT.				MALT.				Average corrected M.L. calen- of dry matter.	Farm.	No.		
	Raw Gms.	% Water	Dry Gms.	M.L.	Raw Gms.	% Water	Dry Gms.	M.L.	Raw Gms.	% Water	Dry Gms.	M.L.	Raw Gms.	% Water	Dry Gms.	M.L.					
1	300	13	261	245.1	1.0	240.4	7.9	244.9	2.6	238.6	8.7	240.6	2.9	233.6	10.5	239.6	1.7	235.5	9.8	Hope, Sir Harry	1
2	300	13	259	245.9	2.3	240.3	7.3	246.6	2.8	239.7	7.6	240.1	3.1	232.7	10.2	240.7	1.7	236.6	9.4		(1)
3	300	14	255	246.7	2.5	240.5	6.4	245.9	2.2	240.5	5.8	242.0	3.2	234.3	8.2	239.8	1.6	236.0	8.3	(2)	
4	300	14	257	244.7	2.3	239.1	7.2	246.2	2.7	239.6	7.0	241.2	2.0	234.2	9.1	240.4	1.6	236.6	7.5	(3)	
5	300	14	257	245.6	2.4	239.7	6.5	247.3	2.6	240.9	6.3	242.3	3.0	235.0	8.6	240.2	1.3	237.1	7.2	(4)	
6	300	14	265	246 "	2.5	240.5	6.7	247.3	2.6	243.7	5.9	242.8	2.9	235.8	6.9	240.2	1.3	237.1	7.3	(5)	
7	300	11	265	247.8	2.6	241.4	8.5	250.2	2.6	243.7	7.3	242.8	2.9	235.8	11.3	241.5	1.4	238.1	10.4	(6)	
8	300	11	266	247.4	2.7	240.7	8.2	246.5	2.8	239.6	9.7	242.6	3.0	235.3	11.3	240.1	2.0	235.3	11.3	(7)	
9	300	13	266	247.4	2.7	240.7	8.5	248.0	2.8	241.1	9.4	244.0	3.1	236.4	11.2	242.8	1.3	239.7	10.8	(8)	
9	300	13	259	241.7	2.3	236.1	8.2	237.9	2.7	231.5	10.7	234.7	2.7	228.4	11.8	235.5	1.9	231.0	10.8	Hasler, W. (1) ...	(1) ...
																				9.7	9

Index No.	BARLEY.				MALT.				MALT.				MALT.				Average corrected M.L. calou-lated as a % of dry matter.	Farm.	No.				
	Raw Gms.	Water %	Dry Gms.	%	Raw Gms.	Water %	Dry Gms.	M.L. %	Raw Gms.	Water %	Dry Gms.	M.L. %	Raw Gms.	Water %	Dry Gms.	M.L. %							
10	300	14.5	256.5	240.1	2.3	234.6	8.5	240.2	2.6	234.0	8.8	234.4	2.8	227.8	11.2	235.1	1.5	231.6	9.7	8.5	Hasler, W. 2)	...	10
11	300	12.7	261.9	238.1	2.4	232.4	11.3	239.9	2.2	234.6	10.4	233.6	2.9	226.8	13.4	235.4	1.8	231.2	11.7	10.5	Do. (3)	...	11
12	300	13.3	260.1	241.0	2.6	234.8	9.7	239.0	2.4	233.3	10.3	236.2	3.0	229.1	12.0	236.7	1.7	232.7	10.5	9.5	Do. (4)	...	12
13	300	14.7	255.9	241.2	2.7	234.7	8.3	240.5	2.4	234.7	8.3	238.3	3.0	231.2	9.5	237.8	1.7	233.8	8.6	7.8	Do. (5)	...	13
14	300	12.9	261.3	242.4	2.5	236.4	9.5	241.0	2.4	235.2	10.0	241.9	2.9	234.9	10.1	239.4	1.8	235.1	10.0	8.9	Davy, A. E. (1)	...	14
15	300	13.4	259.8	242.0	2.4	237.2	8.7	241.6	2.4	235.8	9.2	239.3	3.0	232.1	10.7	239.0	1.6	235.2	9.5	8.5	Do. (2)	...	15
16	300	12.3	263.1	242.9	2.1	237.8	9.6	245.0	2.2	239.6	8.9	238.1	3.0	231.0	12.2	238.5	1.2	235.6	10.4	9.2	Do. (3)	...	16
17	300	12.2	263.4	241.4	2.4	235.6	10.5	241.5	2.3	236.0	10.4	238.1	2.6	231.9	12.0	238.3	1.5	234.7	10.9	9.8	Do. (4)	...	17
18	300	12.8	261.6	244.0	2.4	238.1	9.7	242.9	2.1	237.8	9.1	238.5	2.8	231.8	11.4	237.6	1.2	234.8	10.2	8.8	Do. (5)	...	18
19	300	13.1	260.7	227.2	2.2	232.0	11.0	235.4	2.3	230.0	11.8	231.6	3.0	224.7	13.8	234.8	1.7	230.8	11.5	10.7	Neville, G. H. (2)	...	19
20	300	14.2	257.4	238.0	2.5	232.0	9.9	236.6	2.0	231.9	9.9	232.2	3.0	225.2	12.5	234.3	1.9	229.9	10.7	9.6	Do. (3)	...	20
21	300	14.3	257.1	226.9	2.2	231.7	9.9	236.1	2.1	231.1	10.1	231.8	3.0	224.9	12.5	234.0	1.6	230.3	10.4	9.5	Do. (5)	...	21
22	300	12.5	262.5	238.5	2.1	233.5	11.0	238.0	1.9	233.5	11.0	231.5	2.8	225.0	14.3	233.1	1.9	228.7	12.9	11.0	Do. (1)	...	22
23	300	11.9	264.3	237.6	2.2	232.4	12.0	239.1	2.2	233.8	11.5	233.1	3.0	226.1	14.4	233.0	1.7	229.0	13.5	11.5	Do. (4)	...	23
24	300	13.3	260.1	239.5	2.6	233.3	10.3	243.2	2.9	236.2	8.7	235.7	2.9	228.9	12.0	237.7	1.7	233.7	10.1	9.8	Craig Tanner, E. (1)	...	24

25	300	13	6	259	2	240	4	2	4	234	6	9	5	240	8	2	9	233	8	9	8	235	5	3	0	228	4	11	8	236	3	1	6	232	5	10	3	9	2	Do.	(2)	...	25
26	300	13	5	259	5	240	6	2	5	234	6	8	7	238	0	2	3	232	5	9	8	234	2	3	6	225	8	13	0	238	5	1	6	234	7	9	1	10	0	Do.	(3)	...	26
27	300	13	2	260	4	240	4	2	5	234	4	10	0	242	0	3	0	234	7	9	8	240	3	3	3	232	4	10	8	240	1	1	5	236	5	9	2	8	0	Do.	(4)	...	27
28	300	13	4	259	5	240	8	1	8	236	5	9	0	242	8	2	8	236	0	9	8	232	0	3	4	224	1	13	7	238	5	1	7	234	5	9	7	9	2	Do.	(5)	...	28
29	300	13	7	258	9	240	9	2	3	235	4	8	2	241	3	3	0	234	1	9	6	237	0	3	0	229	9	11	2	238	5	1	7	234	5	9	4	8	8	Edwards, W. H. (1)	(1)	...	29
30	300	13	2	260	4	241	2	2	4	235	4	9	6	241	8	1	9	237	2	8	8	236	3	3	1	229	0	12	1	235	9	1	9	231	4	11	1	9	3	Do. Superphosphate only	(5)	...	30
31	300	15	0	255	0	239	7	2	3	234	2	7	3	240	3	2	7	233	8	8	8	236	4	3	8	227	4	10	8	238	5	1	7	234	5	8	0	7	6	Do.	(5)	...	31
32	300	14	3	257	1	242	0	2	0	237	2	7	8	241	5	2	7	235	0	8	8	235	9	3	1	228	6	11	1	237	8	1	6	234	0	9	0	8	1	Pretzman, E. G., the Rt. Hon. (1)	(1)	...	32
33	300	14	1	257	7	239	1	2	7	232	6	8	6	241	9	2	7	235	4	8	8	235	2	3	4	227	2	11	8	237	5	1	8	233	2	9	5	8	8	Do.	(2)	...	33
34	300	14	2	257	4	238	7	2	6	232	5	9	7	241	7	2	9	234	7	8	8	235	9	3	3	228	1	11	3	236	4	1	8	232	2	9	8	8	8	Do.	(3)	...	34
35	300	13	6	259	2	238	2	2	2	233	0	10	1	239	5	3	0	232	3	9	8	236	3	3	0	229	2	11	4	236	5	1	7	232	5	10	3	9	5	Do.	(4)	...	35
36	300	13	7	258	9	241	4	2	5	235	4	9	1	240	5	2	7	234	0	9	6	235	2	3	4	227	2	12	2	235	8	1	5	232	3	10	8	9	2	Do.	(5)	...	36
37	300	13	6	259	2	237	7	2	4	232	0	10	5	238	9	2	9	232	0	9	8	230	4	3	2	223	0	14	0	235	5	1	4	232	2	9	9	10	1	Do. Dried Seed	(5)	...	37
38	300	14	9	255	3	238	5	2	6	232	3	8	7	237	8	2	6	231	6	8	8	233	7	2	9	226	9	11	1	234	9	1	9	230	4	9	7	8	7	Bembridge, C. (1)	(1)	...	38
39	300	15	5	253	5	236	5	2	0	231	8	8	6	240	3	2	5	234	3	7	6	234	3	2	8	227	7	10	2	233	6	1	8	229	4	9	5	8	0	Do.	(2)	...	39
40	300	15	5	253	5	235	8	2	4	230	2	9	5	236	1	2	3	230	7	9	0	230	9	3	0	224	0	11	4	233	2	1	9	228	8	9	7	8	8	Do.	(3)	...	40
41	300	16	9	249	3	237	7	2	5	231	8	7	0	238	2	2	8	231	5	7	1	235	3	3	4	227	3	8	8	236	3	1	6	232	5	6	8	6	6	Do.	(4)	...	41
42	300	16	4	250	8	238	0	4	4	227	5	9	3	236	7	2	4	231	0	7	9	232	2	3	2	226	7	9	6	232	1	1	7	228	2	8	6	8	0	Do.	(5)	...	42
43	300	11	9	264	3	242	0	2	5	236	0	10	7	239	8	2	6	233	6	11	6	236	7	3	2	229	1	13	3	236	9	1	4	233	6	11	6	10	6	Hill, W. (1)	(1)	...	43
44	300	10	6	268	2	240	1	2	7	233	6	12	9	239	3	2	6	233	1	13	1	236	3	3	3	228	4	14	8	234	6	1	5	231	1	13	8	12	2	Do.	(2)	...	44

Index No.	BARLEY.				MALT.				MALT.				Average corrected M.L. calculated as a % of dry matter.	Farm.	No.
	Raw Gms.	Water %	Dry Gms.	Raw Gms.	Raw Gms.	Water %	Dry Gms.	M.L. %	Raw Gms.	Water %	Dry Gms.	M.L. %			
45	300	11.8	264.6	238.0	2.3	232.5	12.1 10.9	12.0 11.3	238.5	2.4	232.8	14.3 11.4	11.4	Hill, W. (3) ...	45
Control: 1A	300	10.4	268.8	253.6	2.6	247.0	8.1					Step 7.			
Piece 1A. (26)	Qrs. 300	10.4	268.8	255.0	2.3	249.3	7.3								
					Correction —										
					z: y :: 8.1 : 7.3.										
Control: 1B	300	10.5	268.5						252.3	2.4	246.2	8.4			
Qrs. 300	10.5	268.5							253.5	2.4	247.4	7.9			
Piece 1B. (28)					Correction —										
					z: y :: 8.4 : 7.9										
Control: 1C	300	10.5	268.5						245.9	2.9	238.8	11.1			
Qrs. 300	10.5	268.5							250.7	2.3	244.9	8.8			
Piece 1C. (30)					Correction —										
					z: y :: 11.1 : 8.8										
Control: 1D.	300	9.6	271.2												
Qrs. 300	9.6	271.2							250.1	1.45	246.5	9.1			
Piece 1D. (32)									252.75	2.0	247.7	8.7			
					Correction —										
					z: y :: 9.1 : 8.7										

	Step 2.			Step 4.			Step 6.			Step 8.													
46	300	12-1	203-7	237-5	1-9	233-1	11-0	236-9	2-2	231-7	12-1	238-2	2-9	231-2	12-3	238-0	1-6	234-2	11-2	10-2	Hill, W. (4)	...	46
47	300	12-2	263-4	236-1	2-0	231-4	12-1	236-6	2-4	230-9	12-3	237-8	2-9	230-9	12-3	238-7	1-5	235-1	10-7	10-2	Do. (5)	...	47
68	300	11-0	267-0	241-9	2-7	235-4	11-8	239-1	2-3	233-6	12-5	240-0	2-9	233-0	12-7	240-4	2-3	234-9	12-0	10-6	Woburn Experimental Farm.	...	68
69	300	11-55	265-3	240-6	2-4	234-8	11-5	235-9	2-3	230-5	13-1	236-5	2-6	230-4	13-2	241-0	1-5	237-4	10-5	10-7	Do.	...	69
70	300	12-0	264-0	235-0	2-5	229-1	11-5	234-1	2-6	228-0	13-6	238-1	2-8	231-4	12-4	235-0	2-3	229-6	13-0	11-3	Do.	...	70
71	300	11-62	265-1	237-7	2-4	232-0	12-5	235-7	2-4	230-1	13-2	236-5	2-7	230-1	13-2	236-4	2-3	231-0	12-9	11-3	Do.	...	71
72	300	11-25	266-2	238-9	1-9	234-4	11-9	235-7	2-3	230-3	13-5	238-4	2-8	231-7	13-0	238-7	1-8	234-4	11-9	10-9	Do.	...	72
73	300	12-0	264-0	235-7	2-3	230-3	12-8	236-1	2-3	230-7	12-9	237-5	2-9	230-6	12-7	240-4	1-6	236-6	10-4	10-5	Do.	...	73
74	300	13-0	261-0	235-7	2-3	229-7	12-0	232-9	2-1	228-0	12-6	236-8	3-0	229-7	12-0	239-6	1-9	235-1	9-9	10-0	Do.	...	74
75	300	13-1	260-7	231-8	2-0	227-2	12-9	231-2	2-4	225-7	11-2	237-7	3-1	230-4	11-6	238-1	1-7	234-1	10-2	10-4	Beaven, E. S.	...	75
76	300	12-35	263-0	232-7	2-5	226-9	13-7	234-4	2-3	229-0	12-9	237-8	2-8	231-2	12-1	240-6	2-0	235-8	10-3	10-6	Do.	...	76
77	300	11-7	264-9	238-9	1-7	234-9	11-3	232-6	2-3	227-3	14-2	235-9	2-9	229-1	13-5	239-2	1-9	234-7	11-4	10-9	Do.	...	77
78	300	12-35	263-0	232-6	2-1	227-7	13-4	232-1	2-6	226-1	11-5	236-0	2-8	229-4	12-8	235-7	2-2	233-5	12-4	11-5	Do.	...	78
79	300	11-96	264-0	233-5	2-3	228-1	13-6	234-3	2-7	228-0	13-6	237-5	2-9	230-6	12-7	240-5	2-1	235-5	10-8	10-9	Do.	...	79
80	300	11-74	264-8	235-2	2-8	230-5	13-0	233-7	2-7	227-4	14-1	238-2	2-8	231-5	10-3	238-6	2-2	233-4	11-9	11-1	Do.	...	80
81	300	12-2	263-4	237-7	2-0	233-0	11-5	239-0	2-4	233-3	11-4	238-9	2-8	232-2	11-8	238-9	1-1	236-3	10-3	9-7	Rothamsted Experimental Station.	...	81
82	300	11-8	264-6	238-3	2-1	233-3	11-8	232-6	2-4	227-0	14-2	238-3	2-8	231-6	12-5	238-3	1-1	235-7	10-9	10-6	Do.	...	82
83	300	11-6	265-2	241-3	1-9	236-7	10-7	236-4	2-3	231-0	12-9	240-7	2-7	234-2	11-7	239-3	1-4	236-0	11-0	10-0	Do.	...	83
84	300	11-2	266-4	238-9	1-9	234-4	12-0	239-3	2-1	234-3	9-8	241-5	2-7	235-0	11-8	239-5	1-5	235-9	10-9	10-2	Do.	...	84

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THE INSTITUTE OF BREWING RESEARCH SCHEME.

SECOND REPORT ON THE EXPERIMENTS ON THE INFLUENCE OF SOIL, SEASON AND MANURING ON THE QUALITY AND GROWTH OF BARLEY.

1923.

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(Director, Rothamsted Experimental Station, Harpenden.)

IN the first report issued last year a full account was given of the scope of this inquiry and of the methods proposed for adoption. The present report gives the results of the second season's experiments, and shows how far they agree and in what ways they differ from those of last year; field observations which may throw light on any apparent discrepancies are also included. It is as yet too early to attempt any full discussion or to draw general conclusions.

The purpose of the experiments is to ascertain the influence of environmental conditions, such as soil, season and manuring, on the yield and quality of barley.

The experimental scheme comprises five plots, which are as follows :—

- 1.—No manure.
- 2.—Complete artificials : 1 cwt. sulphate of ammonia, 3 cwt. superphosphate, $1\frac{1}{2}$ cwt. sulphate of potash per acre.
- 3.—Artificials without potash : 1 cwt. sulphate of ammonia, 3 cwt. superphosphate per acre.
- 4.—Artificials without phosphate ; 1 cwt. sulphate of ammonia, $1\frac{1}{2}$ cwt. sulphate of potash per acre.
- 5.—Artificials without nitrogen : 3 cwt. superphosphate, $1\frac{1}{2}$ cwt. sulphate of potash per acre.

For reasons given in the last report it is not yet possible to duplicate plots on the farms. The experiments on each farm are, except where otherwise stated, comparable with those of last year, and the checks described in last year's report show that a considerable degree of probability attaches to the results.

At each centre the barley is grown in its accustomed place in the rotation. This, of course, introduces an element of difference between

the various centres, but it ensures that the experimental conditions are truly representative of those generally obtaining in the district. It would have been possible, of course, to eliminate this difference by arranging for the barley to follow the same prescribed crop in all cases, but this would have added an element of artificiality that would detract greatly from the results.

The centres are practically the same as for last year, and it is much hoped that the farmers now in the scheme will continue. They are:—

Eastern Side—

- 1.—Rothamsted Experimental Station, Harpenden, Herts.
- 2.—Beds. Woburn Experimental Farm. Dr. J. A. Voelcker.
- 3.—Essex. Dunmow.* W. Hasler, Esq., Barnston Lodge Farm (G. Bellfield, Esq.).
- 4.—Suffolk. Howes Farm, Martlesham. Rt. Hon. E. G. Pretyman, Esq., Orwell Park.
- 5.—Norfolk. East Dereham. B. Hill, Esq., Hall Farm, Gressenhall.
- 6.—Norfolk Experimental Station, Newton St. Faith. C. Heigham, Esq.
- 7.—Lincs. Wellingore. G. H. Nevile, Esq.
- 8.—Lincs. Walcott. C. Bembridge, Esq.
- 9.—Lincs. Cawwell. Scamblesby. A. E. Davy, Esq.
- 10.—E. Yorks, Beverley. J. H. Spilman, Esq., Gardham Farm.
- 11.—East Lothian. Barneyhill. Sir Harry Hope.

Western Side—

- 12.—Shropshire. Eyton-on-Severn. E. Craig Tanner, Esq.
- 13.—Shropshire. Newport. Harper Adams College. Dr. C. Crowther.
- 14.—Stoke-under-Ham. R. A. Clarke & Sons, Chiselborough.
- 15.—Wiltshire. Warminster. E. S. Beaven, Esq.

Messrs. Eger, of Northolme, and W. H. Edwards, of Milverton, had no suitable land in their barley break this year, but as against these losses a centre was found on the Yorkshire Wolds, where Mr. Spilman laid down an admirable series of plots; another was found in Somerset

* By an unfortunate accident the wrong seed was sown on the Dunmow plots; instead of the selected Beavens Plumage Archer another Beaven barley was grown. The results are therefore excluded from all the general averages and no valuations were made.

at Stoke-under-Ham, where the Messrs. Clarke have rendered valuable service; and new and important types of conditions are being tested at the Norfolk Experimental Station and at the Harper Adams Agricultural College, thanks to the cordial co-operation of the heads of those Institutions.

It is satisfactory to report that the sites are on the whole even better than those of last year and that the farmers showed a keen desire to benefit by their experience so as to improve the experiment wherever that was possible. Moreover the seed and manures were available at a much earlier date, so that farmers were able to sow at the time which they considered best. There were no cross-cropped centres this year; in every case the previous conditions had been uniform.

The Season.

The growing season of 1922 had been hot and dry in its early part, but cold, wet and sunless from July onwards. The season of 1923 differed considerably from this: in spring and early summer it was cold, sunless and dry; from July onwards it was warmer and more sunny, though still as a rule dry until the last fortnight in August, when there was more rain. The data for Rothamsted are given in Appendix II.

The effect of these differences from 1922 was rather curious; yields at the Eastern centres which were not high above sea-level—Dunmow, Orwell Park, Dereham, Walcott and East Lothian—were all substantially less than in 1922; the yields in the centre and west—Warminster, Rothamsted, Woburn and Eyton—remained approximately the same as in 1922, while those of the higher lying Eastern centres—Wellingore and Cawkwell—were above last year's results. The quality at Orwell and East Lothian was distinctly below that of last year, while that of Warminster, Rothamsted, Woburn, Wellingore and Cawkwell was distinctly above it.

The Results obtained.

The figures for yield are given in Table I. In contradistinction with last year there had been no cross-cropping, so that all the results are brought into the one table. It will appear from the subjoined discussion that out of the whole of the 74 plots only four appear to present irregularities, viz., Plots 5 (*i.e.*, the end plot at each centre) at Dunmow, Stoke-under-Ham, Cawkwell and Walcott, which are respectively 11,

25, 12 and 12 per cent. below the unmanured instead of being equal or slightly superior to it. This is evidence that the plots were well chosen and the figures trustworthy.

The yields on the unmanured plot vary from 7·6 to 63 bushels of dressed grain per acre, as against 16·2 and 78·5 for last year, the extremes again being Orwell Park and Barneyhill. As in 1922, Barneyhill far exceeds all other centres in yield. The Orwell Park result is unusually low; next above it come a group of centres, the two in Norfolk, Rothamsted, and Newport, Salop, where the yield is 21½ to 22 bushels.

As in 1922 the effect of the complete fertiliser was to raise the yield excepting only in two cases, Dunmow and Walcott, where, as in last year's experiments, the manures were without important effect. The amount of the increase produced by the complete fertiliser is as follows:—

					Bushels per acre.	Per cent.
Rothamsted	....	....	...	...	11·4	49
Barneyhill	....	....	...	...	9·0	14
Eyton-on-Severn	...	...	...	...	14·2	45
Wellingore	....	....	...	...	5·0	11
Dereham	...	...	...	...	5·0	24
Warminster	...	...	...	...	8·8	25
Newton St. Faith	...	...	...	...	3·7	16
Beverley	...	...	...	...	13·5	37
Newport, Salop	...	...	...	...	8·6	34
Stoke-on-Ham	...	...	...	...	2·0	9
Woburn	...	...	....	...	9·5	28
Orwell Park	...	...	...	...	3·2	38
Cawkwell	...	...	...	...	3·3	9
Mean	...	....	...	...	7·5	26

These increases are, on the whole, higher than were obtained last year, when the values were respectively 5·2 bushels and 16 per cent.

As happened last year the most striking effect is that produced by nitrogenous manure; the sulphate of ammonia has acted in no less than 11 out of the 13 centres where there was any response to fertilisers at all. In 10 out of the 13 centres the manure without nitrogen gave no significant increase in crop; the only cases where the gains were appreciable being Barneyhill, Newport and Eyton. Over the whole series the average increment in yield given by 1 cwt. per acre of sulphate of ammonia has been 4½ bushels, as against 5½ bushels last year and 6½ bushels over a general run of soils and seasons. This conformity to the average affords further evidence that the results on the whole are normal and that the centres may be taken as typical. The lack of any

marked response to potash and phosphates without nitrogen is a normal effect and affords additional evidence of the normality and reliability of the results.

The persistence of the effect of nitrogenous fertilisers in increasing yields is certainly remarkable; it needs only a small number of reliable results to give an average increment of the same order of value as that derived from all available results.

The omission of potash has in no case produced any marked falling off in yield; the only measurable effects were a depression of 3·5 bushels at Barneyhill, 5·7 bushels at Dereham, and 5·3 bushels at Orwell. There was apparently a small gain in yield at Beverley (4·5 bushels); two instances were obtained last year also, and as data accumulate it will be possible to decide whether the difference is significant or not, and, if significant, to obtain some light as to its cause.

The omission of phosphate has been without effect in eight cases, while in six it has led to a small depression averaging 3·4 bushels in yield—a mean value from which none of the six greatly deviates. The six apparently responsive centres are Eyton-on-Severn, Dereham, Beverley, Newton St. Faith, Stoke-under-Ham, Woburn.

The general result as far as yield is concerned is that the nitrogenous fertiliser is the only one which has consistently given increases; phosphate has produced only a small effect, and that only in six out of 14 cases, while potash has had even less action. As was the case in 1922 the only predictable effect is that of nitrogen; the potash and phosphate may produce valuable effects, but the action is more influenced by the season than is that of the nitrogenous fertiliser.

The Valuation of the Crops.

The valuation of the barleys grown on the experimental plots was made on January 8th, 1924, in the same manner as last year and by two of the same sub-Committee, namely, Messrs. Reid and Lancaster, with the help of Mr. Wightman, who took the place of Mr. Cherry-Downes, who was unfortunately unavoidably prevented from serving. The valuers are not informed from which farms the samples come. The results are set out in Table 3. The range of values is from 39s. 6d. to 57s., as compared with 30s. to 65s. last year; the range is considerably narrower, but the general level of quality is higher. In comparing the valuations made in the last two years and generally in considering the Committee's valuations, it is important to keep in mind that the figures represent market values on the date of valuation. It is obviously

impossible to take seasonal fluctuations in market value into account, and the result of this must be that in seasons where such fluctuations take place the Committee's valuations may not represent the average market values for the season. The important point is that the values given are strictly comparable *inter se*.

Comparison of the figures for the two years shows that the soil factor has persisted to some extent in spite of the marked difference in the seasons.

The order of merit of the centres has been :—

1922.	1923.
<i>Highest</i> —Orwell Park.	Rothamsted.
Barneyhill.	Woburn.
Wellingore.	Wellingore.
Eyton.	Barneyhill.
Rothamsted.	Eyton.
Dereham.	Cawkwell.
Cawkwell.	Walcott.
Walcott.	Orwell Park.
<i>Lowest</i> —Woburn.	Dereham.

Orwell and Woburn have suffered considerable change, and Rothamsted a distinct though smaller one, but the other centres are not greatly affected in their relative general merits as barley producers.

The effect of the complete manure, as compared with the unmanured samples, has usually not been very marked. Out of the 13 centres the valuation per quarter is the same as for the unmanured plot in six ; it is 6*d.* more in two cases and 1*s.* more in two cases. At one centre (Woburn) there is the extraordinary difference of 13*s.*

The plots which received no nitrogen were given an increased valuation in four cases, the same valuation in four cases, and a lowered one in five. The plots without potash had the same valuation as those receiving this fertiliser in ten cases : a lower valuation in one case and a higher valuation in two ; those without phosphate were in seven cases valued the same as those receiving phosphate, and in two valued at less. These effects are smaller than were obtained in 1922 when the nitrogenous manure had in some cases a rather harmful effect on valuation, and the phosphate had a more beneficial effect ; in neither season, however, had potash any marked influence.

The Value of the Crops to the Farmer.

These values are set out in Table 5 which has been calculated in the same way as last year. The cost of growing the crop without manure

TABLE 1.—*Making Barley Results, 1923.*

DRESSED GRAIN BUSHELS PER ACRE. (1)

No.	Treatment.	Stiff Soils.		Medium Soils.				Light Soils.				Very Light Soils.		Chalk.	Fen.
		Rothamsted.	Dunmow.	E. Lothian.	Eyton-on-Severn.	Wellingore.	Dereham.	Warminster. (2)	Beverley.	Harper Adams.	Stoke-up-Ham.	Woburn.	Ipewich.	Cawkwell.	Walcott.
1	Nil	21.4	41.3	63.0	33.1	40.8	21.5	$\left. \begin{matrix} 32.0 \\ 36.7 \end{matrix} \right\}$	36.8	22.0	27.0	33.6	7.6	40.0	50.3
2	All	32.8	41.2	72.0	47.3	45.8	26.5	43.1	50.3	30.6	29.0	43.1	10.8	43.3	48.8
3	Less K	33.9	42.8	68.5	47.6	43.8	20.8	42.3	54.8	33.7	26.2	40.6	5.5	44.8	50.0
4	" P	33.8	41.7	73.0	44.4	46.4	22.0	—	46.6	30.2	27.0	38.1	11.2	42.8	47.5
5	" N	19.5	36.8	71.0	40.0	39.2	20.4	35.4	38.6	33.8	19.5	30.5	8.1	35.0	44.1
TOTAL GRAIN UNMANURED = 100.															
1	Nil	100	100	100	100	100	100	100	130	100	100	100	100	100	100
2	All	149	104	114	145	111	124	125	137	134	109	128	138	109	97
3	Less K	153	108	109	148	106	95	123	150	147	100	121	75	112	104
4	" P	154	101	116	137	112	100	—	127	135	98	113	143	108	96
5	" N	90	89	113	119	96	93	103	106	145	75	91	106	88	85
DRESSED GRAIN UNMANURED = 100.															
1	Nil	100	100	100	100	100	100	100 (3)	100	100	100	100	100	100	100
2	All	153	100	114	143	112	123	125	137	139	107	128	142	108	97
3	Less K	158	104	109	144	107	97	123	149	153	97	121	72	112	99
4	" P	158	101	116	134	113	102	—	127	137	100	113	147	107	95
5	" N	91	89	113	121	96	95	103	105	154	72	91	106	87	88

NOTES.—(1.) Bushels of 56 lbs. in all cases.

(2.) Presumably total corn. Percentages worked out on the mean of the two control plots.

(3.) Figures are total grain in this case.

TABLE 2.—Effect of Manuring on Yields.

CHANGE IN BUSHELS PER ACRE IN PLOTS.

	Rothamsted.	Cawthwell.	Dunmow.	Wellington.	Barney-hill.	Dereham.	Eyton-on-Severn.	Beverley.	Warminster.	Stoke-under-Ham.	Harper Adams.	Woburn.	Orwell Park.	Walcott.
Omitting Potash ...	+ 1.1	+ 1.5	+ 1.6	— 2.0	— 3.5	— 5.7	+ 0.3	+ 4.5	— 0.8	— 2.8	+ 3.1	— 2.5	— 5.3	+ 1.2
„ Phosphate ...	+ 1.0	— 0.5	+ 0.5	+ 0.6	+ 1.0	— 4.5	— 2.9	— 3.7	—	— 2.0	— 0.4	— 5.0	+ 0.4	— 1.3
„ Nitrogen ...	— 13.3	— 8.3	— 4.4	— 6.6	— 1.0	— 6.1	— 7.3	— 11.7	— 7.7	— 9.5	+ 3.2	— 12.6	— 2.7	— 4.7
CHANGE IN PERCENTAGE YIELD IN PLOTS.														
Omitting Potash ...	+ 5	+ 4	+ 4	— 5	— 5	— 26	+ 1	+ 12	— 2	— 10	+ 14	— 7	— 70	+ 2
„ Phosphate ...	+ 5	— 1	+ 1	+ 1	+ 2	— 21	— 9	— 10	—	— 7	— 2	— 15	+ 5	— 2
„ Nitrogen ...	— 62	— 21	— 11	— 16	— 1	+ 28	— 22	— 32	— 22	— 35	+ 15	— 37	— 36	— 9

TABLE 3.—VALUATION PER QUARTER OF 448 LB. AS ASSESSED BY VALUATION COMMITTEE.

	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.
No Manure ...	56 0	41 6	—	52 0	50 0	39 6	48 0	43 0	52 0 and 51 0	47 0	42 0	43 0	40 0	41 6
Complete Manure ...	57 0	42 0	—	52 0	49 6	40 0	49 0	41 0	52 0	47 0	42 0	56 0	40 0	41 6
No Potash ...	57 0	41 6	—	53 0	49 6	40 0	49 0	43 0	52 0	47 0	42 0	56 0	40 0	41 6
„ Phosphate ...	57 0	41 0	—	52 0	49 0	40 0	49 0	43 0	—	47 0	42 0	57 0	40 0	42 0
„ Nitrogen ...	56 0	41 6	—	53 0	49 0	40 0	50 0	43 0	52 0	46 0	42 0	58 0	40 0	41 0

TABLE 4.—VALUATION AT EACH INDIVIDUAL CENTRE.

Complete Manure ...	+ 1 0	+ 0 6	—	Nil	— 0 6	+ 0 6	+ 1 0	— 2 0	+ 0 6*	Nil	Nil	+ 13 0	Nil	Nil
Omitting Potash ...	Nil	— 0 6	—	+ 1 0	Nil	Nil	Nil	+ 2 0	Nil	Nil	Nil	Nil	Nil	Nil
„ Phosphate ...	Nil	— 1 0	—	Nil	— 0 6	Nil	Nil	+ 2 0	—	Nil	Nil	+ 1 0	Nil	+ 0 6
„ Nitrogen ...	— 1 0	— 0 6	—	+ 1 0	— 0 6	Nil	+ 1 0	+ 2 0	Nil	— 1 0	Nil	+ 2 0	Nil	— 0 6

TABLE 5.—MONEY VALUES OF THE VARIOUS CROPS.

	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.
Value of Unmanured— Per qr.	56 0	41 6	—	52 0	50 0	39 6	48 0	43 0	52 0 and 51 0†	47 0	42 0	43 0	40 0	41 6
Per acre	155 0	210 0	—	277 0	394 0	114 0	204 0	207 0	239 0 and 204 0	165 0	139 0	182 0	41 0	289 0
Additional per acre for manuring—														
Complete manure ...	84 0	20 0	—	33 0	52 0	28 0	35 0	63 0	59 0	13 0	50 0	121 0	16 0	— 9 0
No Potash ...	91 0	24 0	—	23 0	30 0	— 5 0	100 0	101 0	54 0	— 3 0	68 0	103 0	— 10 0	8 0
„ Phosphate ...	92 0	13 0	—	34 0	53 0	1 0	78 0	55 0	—	— 2 0	50 0	91 0	18 0	— 10 0
„ Nitrogen ...	— 14 0	— 27 0	—	— 5 0	41 0	— 6 0	50 0	11 0	9 0	— 46 0	65 0	39 0	3 0	— 37 0

Figures in italics are those in which a profit is shown.

* Calculated from the mean of the valuations of the two control plots.

† All corn valued as head corn in this case.

TABLE 7.—*Moisture per cent. in Grain.*

Treatment.	Redham- sted.	Cawtwell.	Wellington.	Barney Hill.	Dorham.	Eyton-on- Severn.	Beverley.	Stoke-a- Ham.	Harper Adams.	Woburn.	Orwell Park.	Walcott.
	Moisture. Per cent.	Moisture. Per cent.	Moisture. Per cent.	Moisture. Per cent.	Moisture. Per cent.	Moisture. Per cent.	Moisture. Per cent.	Moisture. Per cent.	Moisture. Per cent.	Moisture. Per cent.	Moisture. Per cent.	Moisture. Per cent.
No Manure	16.36	19.10	15.30	16.15	18.10	16.64	19.05	17.76	18.48	19.38	16.98	17.02
Complete Manure	17.04	18.54	15.34	15.98	18.46	16.54	19.36	17.41	18.98	17.90	15.94	16.64
No Potash	17.80	18.08	15.36	15.92	18.54	16.78	18.90	17.78	18.74	17.70	15.96	16.98
No Phosphate	17.48	19.10	15.06	16.50	18.74	16.34	18.82	17.50	18.20	17.72	16.22	17.64
No Nitrogen	17.00	19.32	14.94	16.36	18.16	16.48	19.68	17.46	17.64	18.72	16.44	18.06
Means	17.54	18.95	15.18	16.18	18.40	16.56	19.16	17.58	18.41	18.80	16.28	17.27

TABLE 8.—*Nitrogen per cent. and Price.*

Treatment.	Redhaunted.	Cawtwell.	Dunmow.	Wellington.	Barney Hill.	Dorham.	Eyton-on-Severn.	Beverley.	Warrminster.	Stoke-a-Ham.	Harper Adams.	Woburn.	Orwell Park.	Walcott.
	Per cent. Nitrogen	Price. Nitrogen.	Per cent. Nitrogen.	Price. Nitrogen.	Per cent. Nitrogen.	Price. Nitrogen.	Per cent. Nitrogen.	Price. Nitrogen.	Per cent. Nitrogen.	Price. Nitrogen.	Per cent. Nitrogen.	Price. Nitrogen.	Per cent. Nitrogen.	Price. Nitrogen.
No Manure	1.707	56	—	1.489	52	1.945	39½	1.318	48	1.293	43	1.327	52	1.889
Complete Manure	1.544	57	2.368	1.464	52	1.994	40	1.337	41	1.364	42	1.354	51	1.815
No Potash	1.549	57	2.217	1.435	53	2.059	40	1.379	43	1.464	42	1.336	47	1.806
No Phosphate	1.578	57	2.365	1.443	52	2.013	40	1.385	43	—	1.744	1.548	47	1.794
No Nitrogen	1.648	56	2.205	1.379	53	2.015	40	1.392	43	1.387	1.800	1.518	46	1.726

Appendix 1—List of Centres with Details.

Centre.	Particulars of soil, field and size of plot.	Previous crop and manuring.	Rate of seedling, sowings, 1923.	Date of application of manures.	Date of cutting.	Approved date of sowing.	Season.
EASTERN SIDE.							
Herts — Rothenhamsted Experimental Station.	Soil clay with flints, heavy strong soil overlying chalk. 1/25-acre plot.	Winter oats. 1 cwt. sulphate of ammonia.	April 20; 10 pecks per acre	April 17	August 21	December 8	See p. 829.
Beds — Wotton Experimental Farm. Dr. J. A. Voelcker.	Sandy loam. Junction of sand and clay. Good, low lying, fertile, wet. Quarter-acre each.	Swedes. F.Y.M.	April 10; 10 pecks per acre	—	Aug 30-31	Nov. 17.	—
Essex — W. W. Hasler, Esq.	Medium to heavy clay loam. Great Barnston Field, three acres each.	Potatoes; 12 loads F.Y.M., 4 cwt. kain dust, 1 cwt. sulphate of potash, 1 cwt. sulphate of ammonia, coverings liberally.	Apr. 4 and 5	Apr. 2 and 3	—	Dec. 10	Only one light sowing causing patchy growth on furrows and rough ground.
Suffolk — Orwell Park Farm. E. G. Petyman, Esq. (Mareham).	Light sand on sand, Homo Field. Two of four acres. Three of half-acre each.	Mustard (folded by sheep)	Apr. 23; 2 bushels per acre.	Apr. 23	—	Nov. 3	Exceptionally dry.
Norfolk — Dereham Hall Farm. B. Gillingham, Esq. Norwich, St. Faith's Experimental Station Farm. C. H. Hedges, Esq.	Light land overlying gravel. One acre each. Light loam overlying chalk. Half-acre each.	Oats; 10 loads F.Y.M., 1 cwt. sulphate of ammonia. Mangolds; 15 loads F.Y.M.	Apr. 10; 12 pecks per acre March 29	Apr. 10 March 28	Sept. 3	Dec. 19	Very dry.
Lincolnshire — Willingore Farm. G. H. Neville, Esq.	Oolite limestone, light loam. About 8 in. soil, 2.53 acres each. Hovel Close Field.	Sugar beets; 10 loads F.Y.M., 3 cwt. super., 2 cwt. kainit, 1 cwt. sulphate of ammonia.	March 19, 20; 10 pecks.	March 22	August 31	Oct. 8 and 9	Dry, following wet winter and March. Good yield. Dry even in February. After sowing till May 24.
Yorkshire — Beverley, Eton Farm. J. H. Spilman, Esq.	Wold land, rather heavy loam over chalk. Plots four acres each.	Mixed green crop (mustard and rape). Eaten off by sheep. Fertiliser which failed and were knocked up.	Apr. 18 and 19; 12 pecks	Apr. 14 and 15.	Sept. 3	Nov. 1	Wet and cold. Many frosty nights.
East Lothian — H. J. Macdonald, Esq. Sir Harry Hope	Red loam, Green Road Field. One acre each.	Swedes; 12 cwt. home-mixed complete artificial.	April 11; 10 pecks per acre.	Apr. 10	Aug. 30	Oct. 20	Cold. High winds May and June.
WESTERN SIDE.							
Shropshire — Adams College, Newport.	Sandy loam overlying lower Trias. Field X North. Plot half-acre each.	Swedes and mustard eaten off by sheep. 2 cwt. super., 1 cwt. kainit.	March 27	April 3	Aug. 30	Jan. 3, 1924	April generally good. A g. period of rain and forcing. Very cold and wet. Good season for winter rain.
Essex — Pyton-on-Severn Farm. J. Craig Thaurer, Esq.	Trias and medium loam. 2 years ago. One acre each.	Winter oats. Slag	March 14; 9 pecks per acre.	April 3	—	—	—
Somerset — St. Andrew-Ham, Chiselborough. Messrs. R. A. Clarke & Son.	Infertile oolite, light sandy soil. One acre each.	Oats and vetches sown. Self-sown after crop fed off by sheep.	April 24; 8 pecks per acre.	April 24	Aug. 16	Oct. 20	Rain immediately after sowing. In the morning bringing barometer down in nine days. One shower of rain. Very dry from sowing to harvest.
Wiltshire — Warminster Farm. E. Beaven, Esq.	—	—	—	—	—	—	—

* Not Plungage Archer, 1922.

the total variation in nitrogen content on the plots at a given centre was usually only about 0·2 per cent. and the valuation of the barley was only to the nearest 6*d.* per quarter. Now these differences in nitrogen content on the different plots are the result of the manurial treatment and illustrate the well-known fact that a farmer can on his own farm alter the percentage of nitrogen in the barley grain within certain limits. The variation that can thus be brought about by manuring is much less marked than that resulting from soil type and climate ; it amounts in these experiments usually to 0·15 or 0·2 per cent., while that from farm to farm exceeds 0·5 per cent. The question arises whether this artificial alteration has the same value in the eyes of the buyer as the natural alteration brought about by different conditions of soil and climate. The buyer was willing to give an additional 2*s.* 9*d.* per quarter in 1922 and 1*s.* in 1923 for every 0·1 per cent. of nitrogen taken out by variation in natural conditions. Will he be willing to give the same increase in price for each 0·1 per cent. of nitrogen which the farmer is able to take out from the grain by varying his manurial scheme ?

The Influence of Manuring on the Nitrogen Content and Valuation of the Grain.

As compared with the unmanured plot the complete manure tends to lower the nitrogen content of the grain ; in a few cases the reverse happens and the nitrogen percentage rises. Of the various constituents the nitrogenous fertiliser usually raises the percentage of nitrogen in the grain, the increase being of the order of 0·1 per cent. ; it also tends to lower the valuation ; in a few cases it lowers the percentage of nitrogen in the grain and then the valuation rises somewhat. In 1922 there had also been, as the result of using nitrogenous fertiliser, an increase in nitrogen content of the grain ranging about 0·1 per cent., the extremes being 0·06 to 0·22. The valuations were usually not affected, but many of the samples were already so low priced that differences in value were of little technical interest. In the case of the better samples (Wellingore and Barneyhill) the increase in average nitrogen content lowered the valuation. Phosphatic fertilisers lowered the percentage of nitrogen in the grain in most cases in 1923 but in three cases only out of eleven in 1922. Curiously enough, this improvement in nitrogen content did not usually in 1923 improve the valuation ; only at Cawkwell and Barneyhill was any increased value awarded, and both

centres are this year somewhat exceptional ; in 1922, however, the barley receiving phosphate obtained a somewhat increased valuation. The effect of potash was in both years much slighter both on per cent. of nitrogen and on valuation.

It appeared from the 1922 results that the valuer is not prepared to offer the farmer as much for reductions in nitrogen content in grain effected by the use of artificial manures as he does for the same reduction effected by soil or climatic agencies. Taking all the results together, the reduction in value for each additional 0·1 per cent. nitrogen resulting from the manurial treatment averaged 10*d.* per quarter as against 2*s.* 9*d.*, when the variation is effected by natural factors. In 1923 a different result is obtained ; the fall in values for each 0·1 per cent. of nitrogen is approximately the same, however the change is brought about. The reduction in value is 1*s.* 3*d.* per quarter when brought about by manuring, and 1*s.* when brought about by soil and season. It is of course of vital importance to ascertain whether the 1922 or the 1923 result is the more normal one ; in other words, whether the valuer is or is not less influenced by a difference in nitrogen percentage caused by manuring than he is by the same difference caused by natural agencies. The analytical work now in progress will show whether or not this is the case, and it may at the same time be expected to explain many of the discrepancies in the so-called nitrogen problem.

The Effect of Season on the Relation between Valuation and Nitrogen Content.

Table 6 shows the average nitrogen content and the valuations for the different centres in 1922 and 1923, and columns have been added in which the values are reduced to a basis of grinding value as 100, the cash basis being 30*s.* in 1922 and 40*s.* in 1923. Only in three cases was the nitrogen content greater in 1923 than in 1922, these being Barneyhill, Orwell and Dereham ; here the relative valuation decreased. In all others the nitrogen content was the same or more usually less ; the relative valuation was the same or more. The detailed order, however, is not the same for changes in valuation as for those in nitrogen content.

TABLE 6.—Comparison of Seasonal Influence and Nitrogen Content—1922 and 1923 at same Centres.

	Nitrogen Averages.			Valuation;				
	1922.	1923.	Differ- ence.	Shillings per quarter.		Relative grinding = 100.		
				1922.	1923.	1922.	1923.	Differ- ence.
Orwell Park	1.51	1.93	+ .42	63.6	40.0	212	100	-112
Dereham	1.65	2.00	+ .35	31.0	39.9	103	100	- 3
Barneyhill	1.44	1.71	+ .27	48.4	49.4	161	123	- 38
Walcott	1.79	1.80	+ .01	30.0	41.5	100	104	+ 4
Rothamsted	1.62	1.61	- .01	32.2	56.6	107	141	+ 34
Cawkwell	1.52	1.49	- .03	29.6	41.5	98	104	+ 6
Eyton	1.92	1.70	- .22	35.2	49.0	117	122	+ 5
Woburn	1.95	1.71	- .24	27.0	54.0	90	135	+ 45
Warminster	1.76	1.49	- .27	37.8	51.8	126	129	+ 3
Wellingore	1.79	1.44	- .35	36.0	52.4	120	131	+ 11

Influence of Manuring on Moisture Content of the Grain.

Reference to Table 7 shows that the average moisture content of the grain from the different farms varied from 15.2 to 19.6 per cent., the order being :—

	Average moisture content.	Average valuation. Shillings per quarter.
Wellingore	15.2	52.4
Barneyhill	16.2	49.4
Orwell Park	16.3	40.0
Eyton	16.6	49.0
Rothamsted	17.2	56.6
Walcott	17.3	41.5
Stoke	17.6	46.8
Dereham	18.4	39.9
Newport	18.4	42.0
Woburn	18.8	54.0
Cawkwell	18.95	41.5
Beverley	19.2	42.6

The order shows little or no correspondence with the valuation, and it is evident that within narrow limits, round about 17 per cent., moisture is less important than nitrogen in influencing the valuer.

APPENDIX II.—Weather of Harvest Year, September, 1922-23, Rothamsted.

The characteristic features of this period were, first, a very dry autumn and, second, a marked deficiency of sunshine and, to a lesser extent, of rainfall, over the spring and early summer. After the harvest of 1922 was gathered, the autumn was very favourable for work on the land. Throughout October and up to the middle of November the rainfall was distinctly below the average; in October only 0·76 in. of rain fell, and there was practically no drainage through the 60-in. gauge except on the last day of the month. The sunshine registered amounted to 140 hours, being 32 in excess of the average. The first half of November gave rise to similar conditions, after which the weather broke and the last fortnight was wet, but not particularly cold. The weather in December was mild on the whole, with sunshine and mean temperature above the average, although 17 ground frosts were experienced. During these months only one small fall of snow occurred, and the prevailing winds came from westerly directions.

Similar mild, fairly dry conditions continued throughout January. The rainfall for this month was 1 in. below the average, the sunshine was slightly in excess of the normal, and the mean temperature was over 3 deg. F. above the average. There were 20 ground frosts but no snow.

The weather definitely changed in February, nearly 4 in. of rain fell—over double the usual amount—and the drain gauge figures show that the soil was saturated during the period. Sunshine was naturally deficient, and the frequent overcast days gave this month a gloomy character, although the weather was not particularly severe. There was no snow, and the mean temperature was above the average in spite of a number of east winds.

March repeated the February conditions, and there was in addition a marked reduction in the number of hours sunshine for this month—76 hours compared with the 112 hours average.

The spring and early summer—April, May, June—were abnormal. The rainfall was below average, especially in June, when only 0·6 in. fell. In spite of this dry weather—usually associated over this period with increased sunshine, the insolation was markedly deficient; in both April and May this deficiency totalled nearly 50 hours, while in June, in spite of one period of summer weather, the total was no less than 88 hours below normal.

The reduction in hours of sunshine was very striking; in fact, over the first six months of 1923 it amounted to a deficit of no less than 225 hours (an average reduction of $1\frac{1}{4}$ hours per day), and it marks the lowest total obtained for this period since 1891, when this station began sunshine records.

The months of July and August showed a change for the better, and the crops benefited considerably, making up some of the arrears of growth. The weather was sunny and warm, and although the rainfall for July was 1.3 in. above the average, no less than 3 in. of the total 3.8 in. fell on three days. The remaining 0.8 in. was fairly evenly distributed in gentle warm showers over the month. The first fortnight of August was a period of drought and the crops suffered somewhat, especially the shallow-rooted ones. The latter half of the month was rainy, but the barley harvest was not seriously checked.

APPENDIX III.—Farmers and Rothamsted Staff Reports on Growing Crops.

PLOTS.

- | | |
|-------------------------|------------------|
| 1.—No Manure. | 3.—No Potash. |
| 2.—Complete Artificial. | 4.—No Phosphate. |
| | 5.—No Nitrogen. |

Rothamsted—

1923.

May 28th.—All plots looking equally well, apparently for a good plant.

June 23rd.—1 plant looks thinner than rest; individual plants poor in appearance, unhealthy dark colour, result of much cold weather. Mildew just appearing.

2.—Appreciable improvement on 1, but still poor in colour.

3.—Indistinguishable from 2.

4.—As for 2 and 3.

5.—Very similar to 1. Mildew noticeable.

July 1st.—1.—Thin, shows little inclination to tiller.

2.—Tillering good, plot as a whole inclined to be patchy. Colour improving.

3.—Growth most advanced morphologically. Tillering comparable with 2.

4.—Not so advanced as 2 in any respect.

5.—Poor still, very glaucous in appearance.

- July 9th.*—1.—Thin in comparison with completely manured, gaps noticeable. Only a few ears out of sheath.
 2.—Straw not very long, but 50 per cent. of ears out of sheath.
 3.—Straw about same as 2. Crop standing less thickly. 80 per cent. of ears out of sheath.
 4.—Slightly less advanced than 2, otherwise very closely comparable.
 5.—Slightly more advanced than 1, but with very few ears out of sheath.

NOTE.—Dry weather has kept the mildew completely in check.

- July 21st.*—1.—Ear thin and short, not completely out of sheath.
 2.—In full ear 2 inches long.
 3.—A little shorter in the ear than 2. Less dense in blade and straw.
 4.—Showing inappreciable differences from 2.
 5.—Thin short ear not completely out of sheath.

Harvesting.

- Aug. 21st.*—1.—Thin crop with short ears.
 2.—Good crop on the whole.
 3.—Nice even crop, not as thick as 2.
 4.—Similar to 3.
 5.—No better than 1.

Woburn—

Crop came up nicely.

- Early June.*—1.—Patchy in appearance.
 2.—Very good-looking plot.
 3.—Not so good as 2. Darker in colour.
 4.—Less good than 3.
 5.—Much less vigorous than 2, 3 or 4.

- Mid. July.*—1.—Signs of later ripening than manured plots 2, 3 and 4.
 2.—Maintains best appearance of all.
 3.—Shows signs of improvement.
 4.—Maintains about the same position as before
 5.—Signs of later ripening than 2, 3 and 4, but will be earlier than 1.

- Harvest.*—1.—Contained fair proportion of green and only partially ripe straw.
 2 5.—Dead ripe.

Dunmow—

Early season.—Very little difference visible Plot 1 (unmanured) seems the poorest.

Orwell Park—

May 19th.—No apparent difference in plots.

Dereham—

May 7th.—No difference apparent.

August 20th.—Barley here caught by moderately dry weather. All crops small. Plot 2 best before drought and still leads by a little.

Wellingore—

Early season.—Plots receiving nitrogen maintain a better colour. Very little difference noticeable otherwise. No phosphate the best, if anything.

September 10th.—Plots harvested, but stubbles show that all plots receiving nitrogen were laid to a greater or less extent, Plot 4 (no phosphate) being the worst. Actually this had the same yield as Plot 2, which had stood up better. Plot 1 (untreated) appeared to have a bigger crop than that receiving potash and phosphates (Plot 5), but the threshing results showed that the excess was only $1\frac{1}{2}$ bushels.

Walcott—

Early season.—No appreciable differences visible.

Cawkwell--

June 4th.-- Looking well on the whole, but a little gappy.

Plots 3 (no potash) and 4 (no phosphate) the best.

Plot 1 (untreated) the poorest.

September 11th.—Plots 3 and 5 stood up best.

Beverley (Furrows Field, Gardham)—

Early season.—Plot 3 (no potash) appeared best.

Plot 5 (no nitrogen) poorest. Differences very slight indeed.

September 12th.—Crop now harvested ; striking effect of nitrogen visible.

East Lothian—

Harvest.—Complete dressing (Plot 2) best. No manure (Plot 1, poorest. The barley looked well throughout the season.

Harper Adams College—

May 15th.—All the manured plots look stronger and thicker on the ground than Plot 1, and the remainder of the field, which is unmanured. Plots 3 (no potash) and 4 (no phosphate) look the strongest.

Eyton-on-Severn—

Early season.—Plot 5 appears best. Plot 1 slightly the poorest. There is no perceptible difference between Plots 2, 3 and 4.

July 14th.—Crop looking well—heading out well.

Plot.

- 1.—Not shot so well as 2.
- 2.—Best of all, distinctly higher, much more out than rest.
- 3.—Not shot quite so freely, and is least out of all the set.
- 4.—A little higher in the straw and a little greener than 5.
- 5.—Very good—more forward than 4.

Chiselborough—

Early season.—No differences.

July 17th.—All looking well—in excellent condition. No differences visible.

St. Faiths—

Early season.—Plot 2 and Plot 3 (complete and no potash) equally better than any others.

Plot 1 poorest.

August 20th.—“No manure” short in straw.

“Complete” is down a little in places,* otherwise looks much the same as the others. Remaining plots look alike.

* Mr. Heigham suggests that in short-necked varieties the casualties, through not getting clear of sheath, are greater than in long-necked varieties.

APPENDIX IV.—Crop Results and Valuations.

Centre.	Treatment.	Dressed grain.		Tail corn.	Value per acre.		Totals.
		Bush, per acre.	at per qr.		Head corn.	Tail at 30s.	
Rothamsted	Nil	21.4	56	81	150	5	155
	Complete Manure	32.8	57	78	239	5	239
	Less Potash	33.9	57	69	241	5	246
	" Phosphate	33.8	57	84	241	6	247
	" Nitrogen	19.5	56	59	137	4	141
	Complete with M/Potash	37.3	58	95	270	6	276
Cawthell	Complete with M/Amm.	35.7	58	91	259	6	265
	Nil	40.0	41½	28	208	2	210
	Complete Manure	43.3	42	42	227	3	230
	Less Potash	44.8	41½	35	232	2	234
	" Phosphate	42.8	41	56	219	4	223
	" Nitrogen	35.0	41½	35	181	2	183
Dunmow	Nil	41.3	—	70	—	—	—
	Complete Manure	41.2	—	187	—	—	—
	Less Potash	42.8	—	177	—	—	—
	" Phosphate	41.7	—	89	—	—	—
	" Nitrogen	36.8	—	70	—	—	—
Wellington	Nil	40.8	52	173	265	12	277
	Complete Manure	45.8	52	173	298	12	310
	Less Potash	43.8	53	151	290	10	300
	" Phosphate	46.4	52	145	301	10	311
	" Nitrogen	39.2	53	173	260	12	272

APPENDIX IV.—Crop Results and Valuations—continued.

Centre.	Treatment.	Dressed grain.		Tail corn.		Value per acre.		Totals.
		Bush per. acre.	at per qr.	lb. per acre.	Head corn.	Tail at 30s.		
Barney Hill, E. Lothian	Nil	63.0	50	Very little	394	Very small	394	
	Complete Manure	72.0	49½	"	446	"	446	
	Less Potash	68.5	49½	"	424	"	424	
	" Phosphate	73.0	49	"	447	"	447	
	" Nitrogen ..	71.0	49	"	435	"	435	
Dereham	Nil	21.5	39½	112	106	8	114	
	Complete Manure	26.5	40	147	132	10	142	
	Less Potash	20.8	40	75	104	5	109	
	" Phosphate ..	22.0	40	77	110	5	115	
	" Nitrogen	20.4	40	82	102	6	108	
Eyton-on-Severn	Nil	33.1	48	72	199	5	204	
	Complete Manure ..	47.3	49	140	290	9	299	
	Less Potash	47.6	49	177	292	12	304	
	" Phosphate	44.4	49	152	272	10	282	
	" Nitrogen ..	40.0	50	60	250	4	254	
Beverley	Nil	36.8	43	130	198	9	207	
	Complete Manure	50.3	41	186	268	12	270	
	Less Potash	54.8	43	210	294	14	308	
	" Phosphate ..	46.6	43	186	250	12	262	
	" Nitrogen .	38.6	43	161	207	11	218	

Warminster*	Nil	{ 36.7 } 32.0	{ 52 } 51	—	{ 239 } 204	{ 239 } 204
	Complete Manure	43.1	52	—	—	—
	Less Potash	42.3	52	—	—	—
	" Nitrogen	35.4	52	—	—	—
Stoke-under-Ham	Nil	27.0	47	84	159	165
	Complete Manure	29.0	47	123	170	178
	Less Potash	26.2	47	123	154	162
	" Phosphate	27.0	47	56	159	163
	" Nitrogen	19.5	46	100	112	119
Harper Adams	Nil	22.0	42	358	115	139
	Complete Manure	30.6	42	418	161	189
	Less Potash	33.7	42	456	177	207
	" Phosphate	30.2	42	450	159	189
	" Nitrogen	33.8	42	406	177	204
Woburn	Nil	33.6	43	9	181	182
	Complete Manure	43.1	56	9	302	303
	Less Potash	40.6	56	10	284	285
	" Phosphate	38.1	57	10	272	273
	" Nitrogen	30.5	58	6	221	221
Orwell Park	Nil	7.8	40	48	38	41
	Complete Manure	10.8	40	48	54	57
	Less Potash	5.5	40	48	28	31
	" Phosphate	11.2	40	48	56	59
	" Nitrogen	8.1	40	48	41	44
Walcott	Nil	50.3	41½	413	261	289
	Complete Manure	48.8	41½	406	253	280
	Less Potash	50.0	41½	564	259	297
	" Phosphate	47.5	42	440	249	279
	" Nitrogen	44.1	41	378	228	252

* No details as to amount of tail corn. All corn valued at head corn price.

Summary.

1. The season was better for barley than in 1922, and at most centres the yield and quality were alike higher.

2. The complete artificial manure raised the yield in all except two cases. The most effective constituent was, as before, the nitrogen; the average increase in yield given by 1 cwt. of sulphate of ammonia was $4\frac{1}{2}$ bushels of grain, as against $5\frac{1}{2}$ last year. Phosphate was effective at nearly half the centres, the 3 cwt. super. giving an average increased yield of 3.4 bushels. Potassic fertilisers, on the other hand, produced measurable effects only on the light soils.

3. The effects of manuring on the valuation were not very consistent. Barleys receiving nitrogen were sometimes valued at less and sometimes at more than those receiving none; barleys receiving phosphate were less often affected but sometimes received more and sometimes less than those without phosphate, while barleys receiving potash were usually valued at the same as those receiving none.

4. The relationship between the valuation and the nitrogen content of the grain, when comparing barleys from the different centres, was less marked than was the case last year. For each additional 0.1 per cent. of nitrogen it was found that the valuers had deducted 1s. per quarter, as against 2s. 9d. last year.

5. In contradistinction to last year's results the valuers attached neither more nor less value to variations in nitrogen content from plot to plot on the same farm than they did to variations from farm to farm. The results showed some irregularity: while the sample with highest nitrogen content had the lowest valuation, and that with the lowest nitrogen had the highest valuation, the intermediate samples did not always fall into line.

The fuller analytical data being now accumulated will show whether the discrimination shown in 1922 between changes in nitrogen content brought about by soil and climate on the one hand, and fertilisers on the other, has a valid basis or whether it was accidental.

6. The nitrogen content of the grain was influenced by the manuring, being usually lowered by phosphate and raised by nitrogen; potash had but little influence. These effects are not simple, as there are some clear cases where they are reversed.

7. The moisture content of the grain was usually less on the plots receiving nitrogen and phosphate than on those not so treated; but it was approximately the same on those receiving potash as on those without it. Within narrow limits of variation round about 17 per cent it appears that changes in moisture content have less effect on valuation than changes in nitrogen content.

THE INSTITUTE OF BREWING RESEARCH SCHEME.

REPORT ON THE ANALYSES OF THE BARLEYS OF 1922 AND THE MALTS MADE FROM THEM.

By H. LLOYD HIND, B.Sc., F.I.C.

THIS Report includes the results of the analyses of the barleys grown under the auspices of the Institute of Brewing Barley Research Scheme in 1922, together with those of the malts made from them; also the analyses of several barleys grown under different manurial treatments at Rothamsted and of some barleys raised by the National Institute of Agricultural Botany, with their malts.

The first season's determinations were necessarily of a rather exploratory nature. The main object of malt analysis is usually to determine the monetary value of brewing raw material, its suitability for some specified type of beer or to control malting operations. Maltsters and brewers are sufficiently agreed on the determinations required for these purposes, and in this country generally make use of the standard methods of analysis laid down by the Malt Analysis Committee of the Institute of Brewing, but the objects of the Research Committee go much further than a mere determination of those figures on which the commercial valuation of malt and barley depends. They seek, among other things, to elucidate the properties of barley on which its malting quality depends and to help in the production of good malting barley by a study of the effects of manurial treatment.

Quality is a very elusive property so far as any strictly numerical evaluation is concerned. Though quantity of extract may be determined with sufficient accuracy and its value in terms of money expressed quite clearly under the assumption that extract is always just extract, there is no established criterion of what constitutes "quality" in extract. Most brewers have quite definite views on what malts suit them and what do not, but knowledge of the factors which govern this preference or dislike, which is based on practical experience, is lamentably lacking in precision. Quality is obviously of paramount importance, and the discovery of criteria for its evaluation are much to be desired.

Analytical valuation of barley is even more rudimentary than that of malt. Ideas seem to circle round the nitrogen content of the grain, and all experience goes to show that percentages of nitrogen above the

normal point to the unsuitability for malting of the barley containing it, but very little is known of the condition in which the nitrogen exists or what influence on malting quality the different classes of nitrogenous constituents may have. The determinations made this year have, therefore, turned very largely on the determination of the total nitrogen in the samples, and an endeavour to correlate it with such quantities as are generally estimated in malt analysis. The value of these is understood, and they obviously form a starting point for exploration into the unknown conditions which ultimately govern and determine "quality." Physical valuation of barley, which, in the hands of experts, is capable of great precision, fails in certain doubtful cases. These analyses indeed provide instances of low valued barleys giving quite useful malts. The elaboration of rapid analytical tests to supplement hand valuation is obviously an achievement greatly to be desired, with these lacking the striving for appearance, and the large increase of price attached thereto may not be altogether favourable to the attainment of the highest quality, and unavoidable defects in appearance are very discouraging to barley growers on account of the consequent low price obtainable for otherwise useful material.

Such a series of barleys from one selected seed as that gathered together by the Committee from widely distributed farms, all cultivated under scientifically planned manurial treatments, has never before been grown, and they provide a wide range of examples of the most varied climatic, geological, geographical and manurial conditions on the growth of one pure race of barley, in this case a selected Plumage-Archer. It has been indicated that the first year's harvest cannot show the full effect of manurial treatment, but the analyses show immense differences in the barleys and malts from different localities, and when these are correlated with the nitrogen content and demonstrated in the curves which have been drawn the close relation between nitrogen and quality is clearly brought out. This is at least one step. It is not new but corroborates all the evidence at present available, and forms a basis for future exploration. There are innumerable possibilities of other lines of research. There would seem, for instance, to be reason to believe that the mineral constituents of barley and the changes which take place in them during malting, giving rise among other things to an increase of acidity through the modification of the phosphates, have considerable influence on the brewing value of malt. These factors have hardly been considered this year, but will no doubt receive attention as time goes on. Investigations into the influence

of selected factors, such as have been indicated, require the accumulation of an immense amount of data bearing on every determinable property of the malts and their subsequent correlation and comparison, and consequently the analytical tables appended to this Report are made as full as possible. It will only be possible to gauge their full import when the results for a series of years are available.

The results of the analyses are set out in tables appended to this Report, and some of the more striking results are plotted in diagrams to show more clearly any differences in the barleys or malts brought about by regional influences operating at the various centres or by the different manurial treatments at each centre. The figures are given in most cases without comment, as it would be premature to draw conclusions from the first year's results other than those referred to by Sir E. J. Russell in his "Report on the Experiments on the Influence of Soil, Season and Manuring on the Quality and Growth of Barley." (See this Journ. 1923, 29, 624.) A full account of the scope of the investigation, the manner in which it is being carried out, details of the different centres at which the barleys were grown, the manurial treatment and the crops obtained, is to be found in that Report. The analyses are the first of a series that it is hoped will be carried out over a number of years, and any deductions that might be drawn from the results or from the diagrams based on them will serve to indicate points that will be more closely examined during succeeding years.

With the exception of the barleys grown by the National Institute of Agricultural Botany, of which analyses are appended, all the samples were grown from the same Plumage Archer seed, and any deductions made refer to this one barley only. Generalisations which apply in this case cannot be assumed to be true if extended to all varieties of barley. Table I gives the analysis of the seed barley.

TABLE I.

Analysis of the Original Seed Barley (sweated).

Moisture per cent.	11.20
Nitrogen per cent. on dry barley	1.472
Nitrogen soluble in alcohol (sp. gr. 0.90) per cent. on dry barley	0.429
Diastatic power, degrees Lintner	21
1,000 corn weight dry barley, grams	44.8

Methods of Analysis.—Malts.—The methods employed were in every case where applicable those prescribed by the Malt Analysis Committee. In the case of diastatic power the Methylene blue indicator introduced by Lane and Eynon was used with very satisfactory results. The permanently soluble nitrogen was determined on the wort made up for extract determination, an aliquot part being boiled for twenty minutes, made up to volume and filtered, 10 c.c. (corresponding very closely to 1 grm. malt) being then taken for the determination. The nitrogen was determined by the Kjeldahl process.

Barleys.—The moisture was determined in a Siau's oven through which a current of hot air is constantly passed. The temperature rises to 97° C. and the barleys are dry in about 2 or 2½ hours. The moistures so determined are about 1 per cent. higher than those obtained in an ordinary steam oven. The barleys were all sweated in bags in a hot room at about 110° F., remaining there for four days. The sweated barleys were then used for malting and the analyses made from samples from them. For details of the malting process and results reference should be made to H. M. Lancaster's Report (see this Journ. 1924, 162).

Nitrogen Soluble in Alcohol.—Munro and Beaven have suggested that the amount of nitrogen soluble in alcohol of sp. gr. 0.9 varies with the maturation or mealiness of the barley, and it was decided to carry out determinations. Ten grms. of the finely ground barley was placed in a stoppered bottle with 100 c.c. alcohol of sp. gr. 0.9 and shaken in an automatic shaker for three hours, filtered, and the nitrogen per cent. determined on 10 c.c. = 1 grm. malt. It was found that the amount of nitrogen dissolved by the alcohol varied with the fineness of the grind. The determinations were carried out under conditions as comparable as possible with a coffee mill and a very constant relation was found to exist between the alcohol soluble nitrogen and the total nitrogen. Further investigation in this direction seems to be desirable with mills that could be set to give a much finer grind. The permanently soluble nitrogen of the malt is also found to bear a constant relation to the total nitrogen as set out in the following table (Table II), in which only the average values for each farm are given. It must be emphasised that this proportionality refers to one variety of barley only, and must not be supposed to hold when comparing different varieties.

TABLE II.

Total Nitrogen of Barleys compared with the Nitrogen soluble in Alcohol of sp gr. 0.90 and the Permanently soluble Nitrogen of the Malt.

Locality.	Nitrogen on dry matter.				
	Total per cent.	Soluble in alcohol. per cent.	Soluble in alcohol as per cent. of total N.	Permanently Soluble. per cent.	Permanently Soluble as per cent. of total N.
Barneyhill ..	1.44	0.42	29	0.50	35
Dunmow	1.77	0.51	29	0.63	36
Cawkwell	1.53	0.42	27	0.51	33
Wellngore ..	1.79	0.49	27	0.62	35
Eyton-on-Severn	1.92	0.52	27	0.62	32
Milvorton ..	1.55	0.40	26	0.54	35
Orwell Park ..	1.51	0.39	26	0.54	36
Walcott	1.79	0.50	28	0.62	35
Dereham ..	1.65	0.47	28	—	—
Northolme ..	2.13	0.59	28	—	—
Woburn ..	1.95	0.54	28	0.69	35
Warrminster ..	1.76	0.41	23	—	—
Rothamsted ..	1.62	0.47	28	0.55	34
.. plot 7/1 ..	1.32	0.30	23	—	—
.. " 7/2 ..	1.79	0.48	27	0.62	35
.. " 6/1 ..	1.26	0.26	21	—	—
and 6/2.					

The third and fifth columns of figures represent the percentage of the total nitrogen which is soluble in alcohol and permanently soluble in the wort respectively. It will be noticed how closely they approximate to constants.

Fig. 1 is a spot diagram on which the extract in brewers' pounds per quarter of 336 lb. of the dry malt has been plotted against the nitrogen percentage of the dry barley. It shows for the sixty-two samples included that an increasing nitrogen content is followed in general by a decreasing extract.

Fig. 2 is a similar distribution diagram for extract and nitrogen, but based on the average values for the five samples at each centre and including the nitrogen percentage of the malts as well as of the barleys.

Fig. 3 gives approximate regression curves for extract and nitrogen based on the averages for each centre, one curve referring to the standard grind with rollers 0.5 mm. apart, and the other to the extract determined from a finely ground grist. To construct this curve the barleys

have been arranged in classes according to their nitrogen content. The classes are as follows:—(1) containing from 1.40 to 1.49 per cent. nitrogen; (2) from 1.50 to 1.59 per cent. nitrogen; and so on (6) being from 1.90 to 1.99 per cent. nitrogen. Where there is a difference between the nitrogen of barley and malt the mean has been taken to decide the class to which that sample belongs. The average dry extract of all barleys falling in each class has been plotted as the ordinate. This figure, which refers to the same sixty-two samples as are

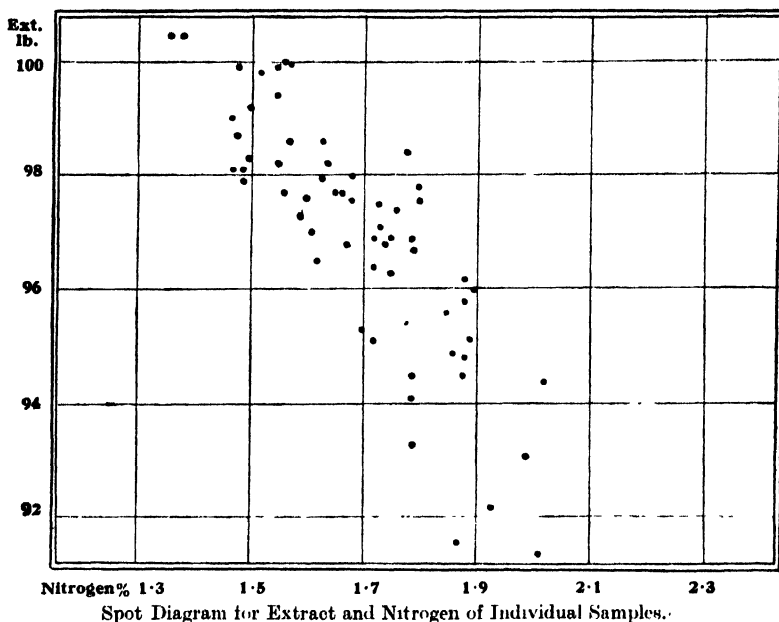


FIG. 1.

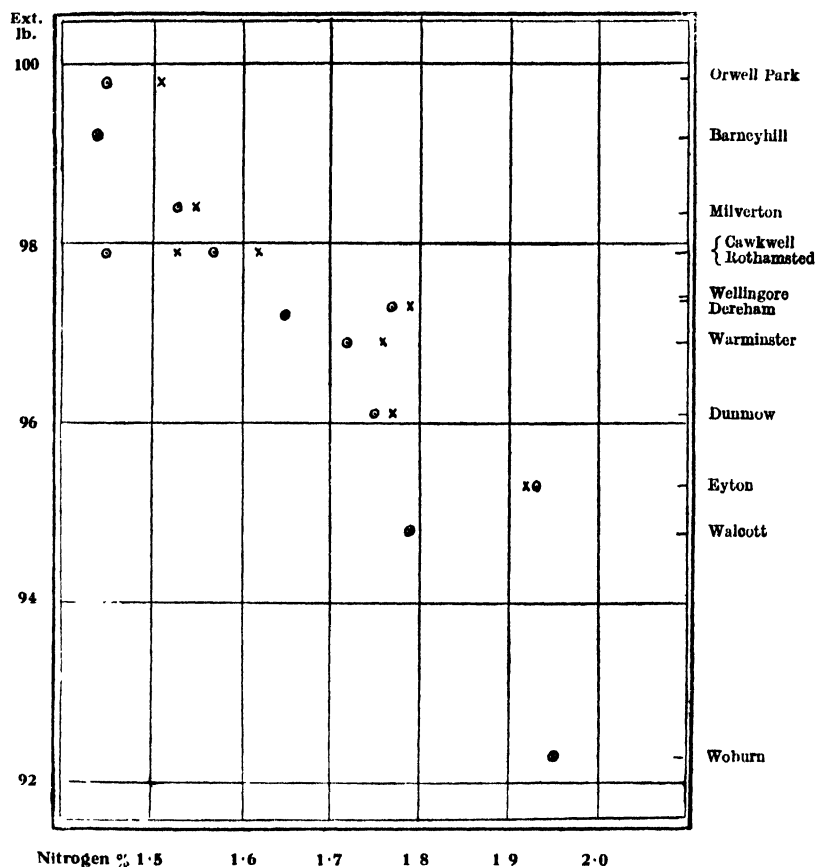
indicated in Figs. 1 and 2, shows even more clearly how closely the extract and nitrogen percentage of the barleys are connected, an increasing nitrogen in the barley involving a decreasing extract in the malt.

Fig. 4 sets out in diagrammatic form the relations which have been found to exist between barley nitrogen, extract of malt, barley market valuation and malt class, the values taken being the averages for each centre set out in descending order of nitrogen. The malt classes and

the corresponding malt valuations are taken from H. M. Lancaster's Report quoted above.

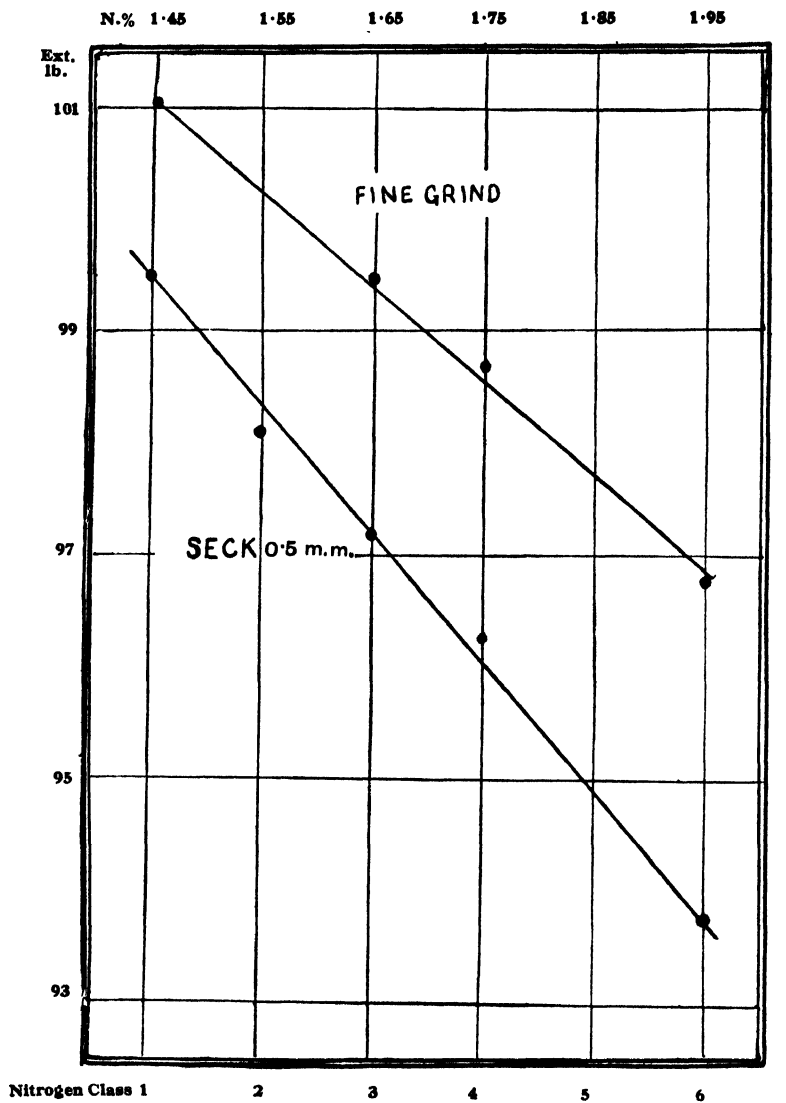
Analyses of Malts and Manurial Treatment of Plots.

The foregoing diagrams give broadly the relation between nitrogen content of the barley and malting quality as indicated by the extract



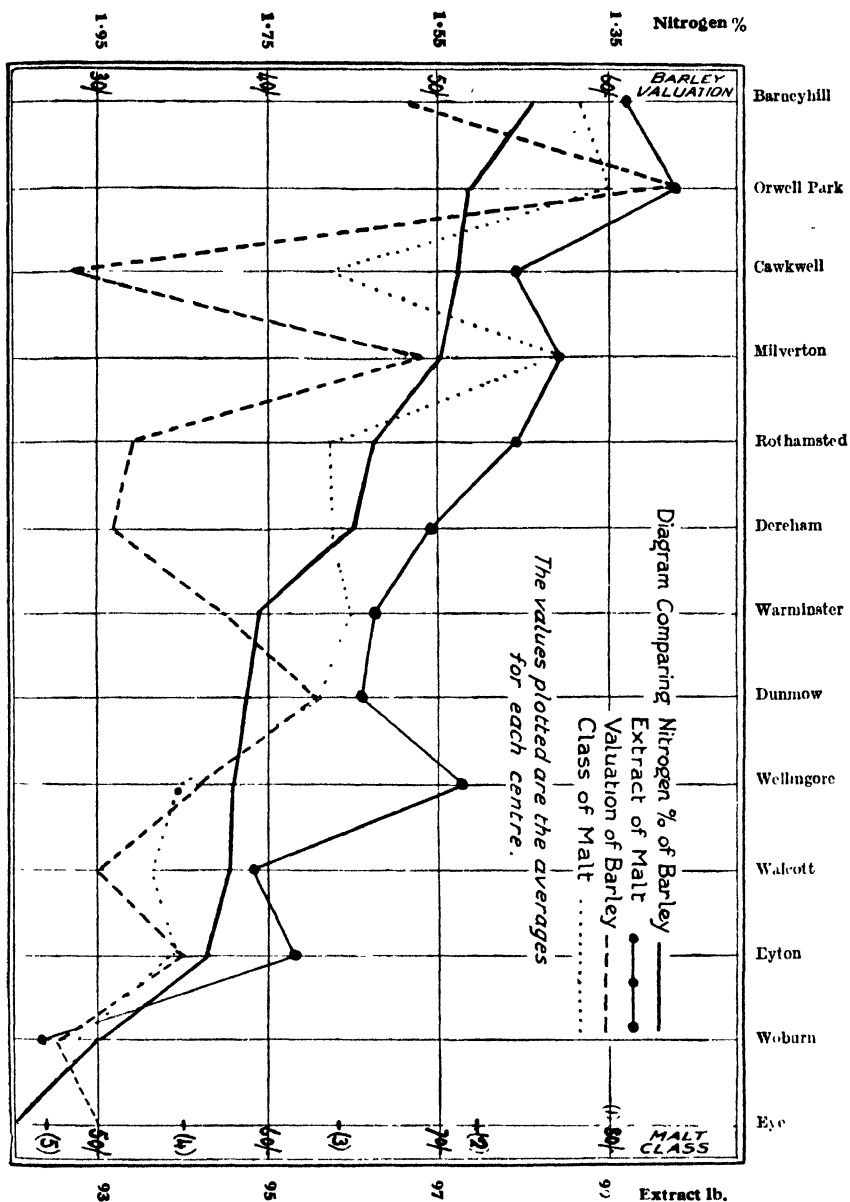
Distribution Diagram for Extract and Nitrogen. Points represent averages for each Centre. N. % on dry barley x. N. % on dry malt o

FIG. 2.



Approximate Regression Curve for Extract on Nitrogen. Averages for each Centre.

FIG. 3.



and valuation of malt, and the effect of locality on the barley produced, but no indication of the effect on quality produced by the various manures employed on the different plots at each farm.

Five plots were planted at each centre manured as follows:—

Plot 1.—No manure.

Plot 2.—Complete artificials: 1 cwt. sulphate of ammonia, 3 cwt. superphosphate, $1\frac{1}{2}$ cwt. sulphate of potash per acre.

Plot 3.—Artificials without potash: 1 cwt. sulphate of ammonia, 3 cwt. superphosphate per acre.

Plot 4.—Artificials without phosphate: 1 cwt. sulphate of ammonia, $1\frac{1}{2}$ cwt. sulphate of potash per acre.

Plot 5.—Artificials without nitrogen: 3 cwt. superphosphate, $1\frac{1}{2}$ cwt. sulphate of potash per acre.

The average values for nitrogen content of dry barley, extract of dry malt and market valuation of barley for each plot over the whole series of farms, are as follows:—

TABLE III.

Plot:	1	2	3	4	5
Nitrogen, per cent. on dry barley	1.646	1.730	1.744	1.713	1.662
Extract of dry malt	96.8	96.7	96.3	96.7	96.8
Barley valuation, shillings	37.5	37.2	37.1	37.3	38.3

This table seems to indicate that the variation produced by different manurial treatments, when considered over all the farms, is small compared with the variations dependent on locality, climate, soil, etc.

Fig. 5.—These average values are plotted in descending order of nitrogen content on a rather open scale to accentuate any effects that manurial treatment may have produced. The general relation between nitrogen, extract and valuation is seen to be very similar to that brought out by the other curves.

Fig. 6.—Includes the nitrogen and extract of the five samples at four of the centres, and shows considerably greater variation from plot to plot than is indicated by the averages over all the centres. The relation between nitrogen and extract is very similar to that to which attention has already been drawn, but greater deviations naturally occur than in Figs. 1 to 4.

Consideration of variations in cultural conditions which are bound to have occurred in the first year's experimental growings makes it undesirable to discuss more closely the results obtained this year for the individual plots of each farm. The average results for each treatment may, however, be expected to eliminate to some extent the discrepancies

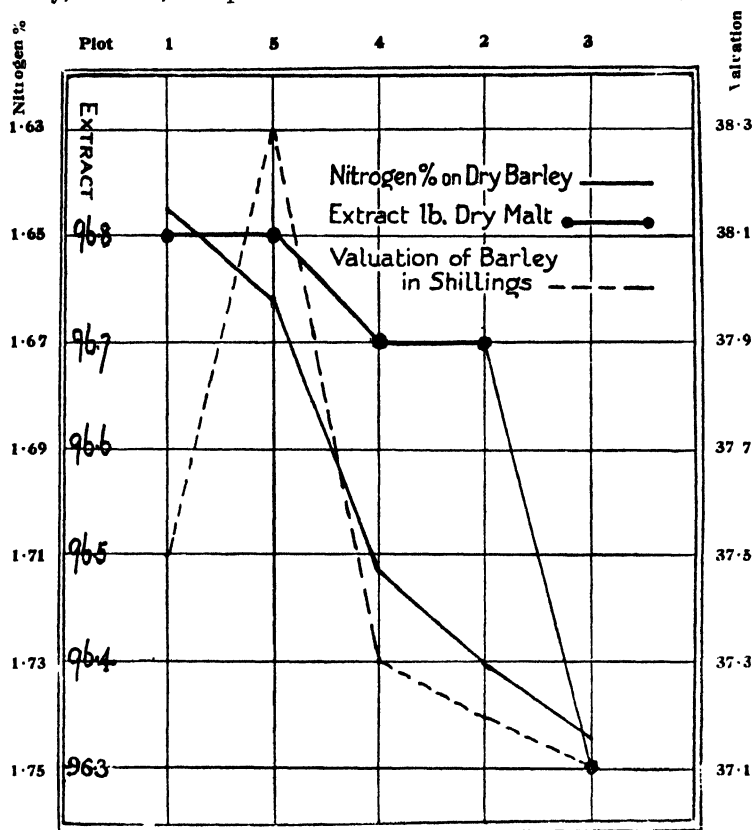


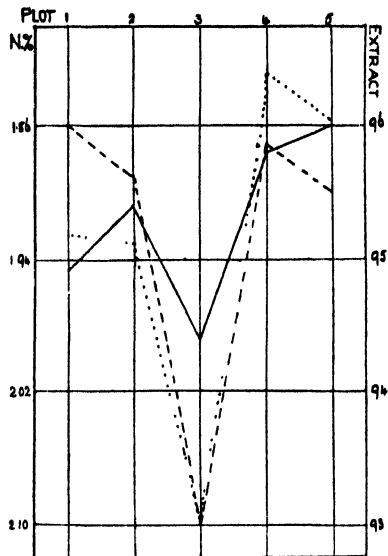
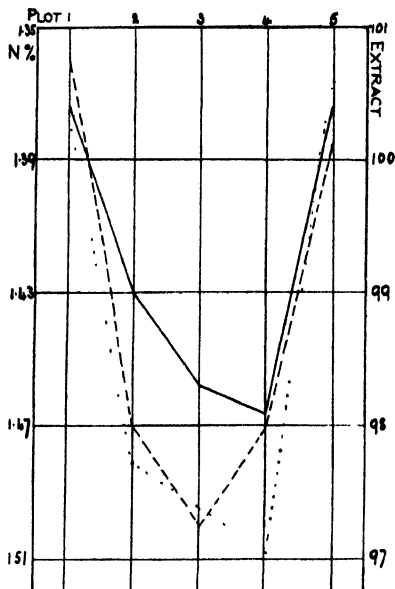
FIG. 5.

Average values for different manurial treatments.

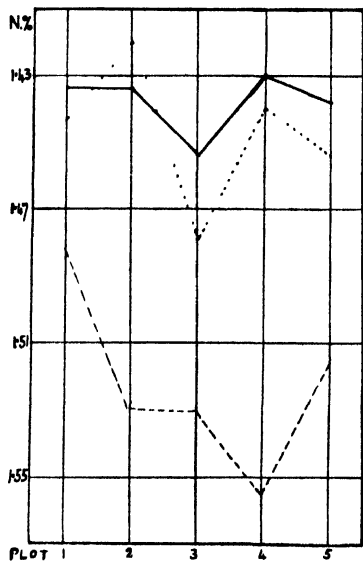
occurring in individual plots, and for that reason they have been set out in detail. Table IV includes the average value for a number of determinations for plots of the same manurial treatment at the following centres: Barneyhill, Dunmow, Cawkwell, Wellingore, Eyton-on-Severn, Orwell Park, Walcott and Dereham.

BARNEYHILL.

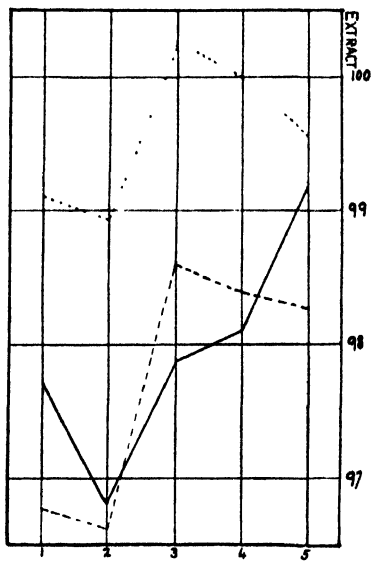
EYTON-ON-SEVERN



ORWELL PARK.



CAWKWELL.



Extract — Nitrogen % on Dry Barley ---- N.% on Dry Malt

TABLE IV.

Plot :	1	2	3	4	5
Nitrogen, per cent. on dry malt	1·624	1·667	1·693	1·670	1·621
Extract of dry malt	97·5	97·1	96·9	97·2	97·4
1,000 corn weight of dry malt, grms.	38·9	38·6	38·2	38·9	39·0
Diastatic Power, degrees Lintner	40·6	41·6	42·0	40·0	41·1
Cold water extract, per cent.	20·0	20·2	20·2	20·4	20·1
Value, shillings, per quarter	65	65	63	65	64

These are plotted for comparison in Figs. 7 and 8.

The following points will be noted :—

Nitrogen.—The lowest nitrogen is found in the malts from barleys grown on plots 1 and 5 (no manure and complete artificials without nitrogen). The highest nitrogen on plot 3 (no potash). Barleys grown with complete manure and without phosphate are intermediate.

Extract.—Corresponding results appear. Plots 1 and 5 give the highest extracts, plot 3 the lowest with 2 and 4 intermediate.

1,000 corn weight.—The curve is similar in regard to plots 1, 2, 3 and 5, but plot 4 falls almost into line with 1 and 5 with the heaviest corns. Plot 3 (with the highest nitrogen and lowest extract) gives the lightest corns.

Diastatic Power.—The treatment of all the samples during malting was as regular as possible, so that any notable variations would be significant. The average values for the different manures are, however, very similar, but it is noticeable that plot 3, corresponding with its high nitrogen, gives the highest diastase. Plot 4 is, however, the lowest and plot 5 does not fall so low as its nitrogen content would suggest.

Cold Water Extract.—There is very little difference in the cold water extracts of the different plots. Plots 1 and 5 give the least, but 4 gives more than 3.

From these results the malts from barleys grown without manure, or with complete artificials without nitrogen, would be picked out as generally the best and those without potash as the worst. The curve in diagram No. 7 representing the class agrees with this in placing that without potash as the worst and that without manure as the best, but plots 2 and 4 are level with the unmanured and the valuation of plot 5 (without nitrogen) is lower than the analytical figures would suggest.

The malt valuation is given in this diagram in terms of the classes adopted in H. M. Lancaster's Report. The five classes are there

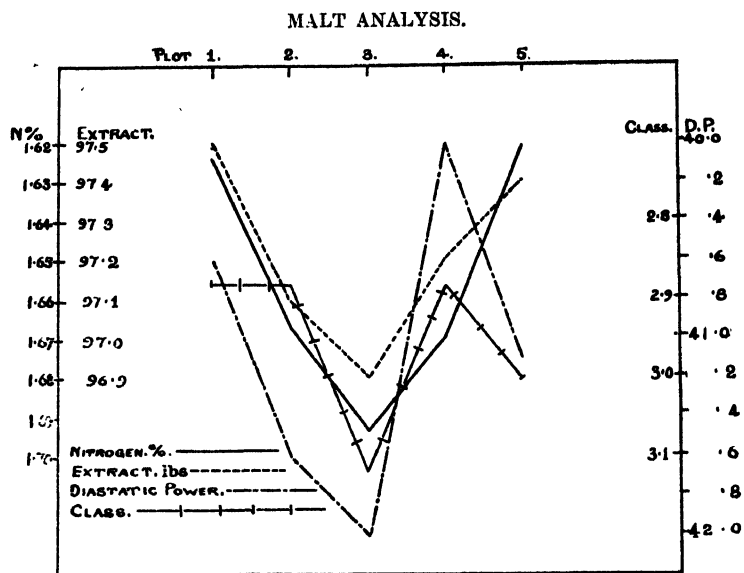


Diagram of Average Values for each Plot at eight Centres.

FIG. 7.

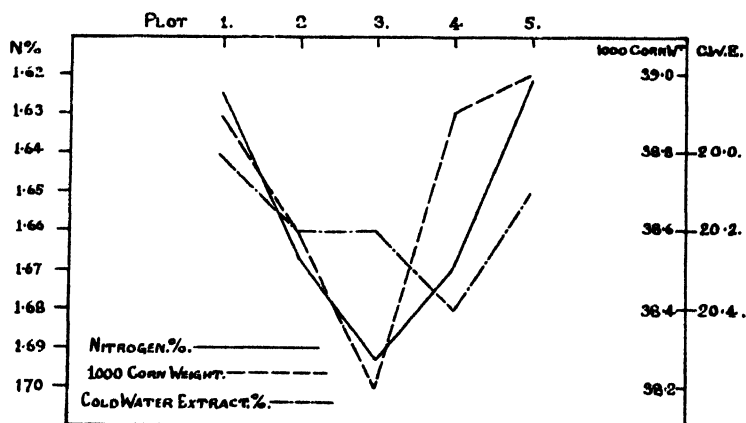


Diagram of Average Values for each Plot at eight Centres.

FIG. 8.

accorded the following approximate valuations based on prices ruling at the date of valuation :—

Class 1 ...	...	...	...	...	80s. per quarter.
Class 2 ...	...	...	...	...	72s. „
Class 3 ...	...	...	...	...	64s. „
Class 4 ...	...	...	...	...	55s. „
Class 5 ...	...	...	...	...	47s. „

In Fig. 4 the value in shillings is given as well as the class.

Rothamsted Barleys.

The same Plumage Archer seed as was used at the other centres was grown at the Rothamsted Experimental Station with various manurial treatments differing from those adopted as the standard for the Research Scheme. Particulars of those selected for malting are given in H. M. Lancaster's Report. The analyses of these are given in this report under the numbers 88 to 127. The most interesting are those grown on the Permanent Barley Plots numbered 7/1, 7/2, 6/1 and 6/2, Nos. 109 to 112 in the accompanying tables.

7/1 has had no manure since 1872. 7/2 has had farmyard manure every year since 1852. 6/1 has had no manure and 6/2 coal ashes only since 1852. For purposes of analysis 6/1 and 6/2 have been blended.

Fig. 9 has been drawn to show the results of their analysis, and it will be noted how much superior the barleys from the unmanured plots were, and the same applies to the malts. The differences in valuation are reflected in the nitrogen curves, while the 1,000 corn weight and diastase curves run parallel with these.

Barleys grown at the National Institute of Agricultural Botany, Cambridge.

These barleys are the results of trials at different centres of various new varieties grown in comparison with Garton's 1917 and Archer. The best barleys at each centre were malted. A number of plots of each barley were grown at each centre, but those of the same variety were bulked before malting. The results obtained this year are very incomplete, but they indicate that at each of the three localities referred to the same barley (Beaven's 1920) had the lowest nitrogen and Golden Pheasant and Cambridge 59/120 the highest. At Market Weighton, Yorks, and Newport, Salop, the extracts run inversely with the nitrogen, the highest extract with the lowest nitrogen and *vice versa*, but the samples from Cambridge did not agree.

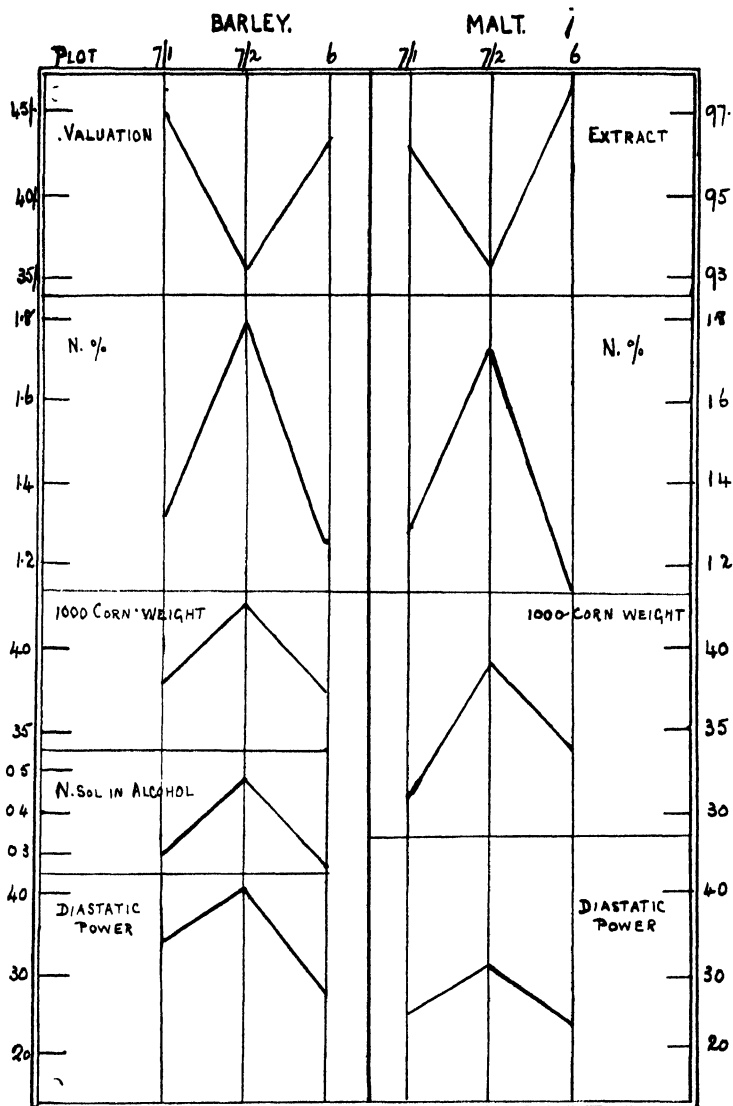


FIG. 9.

PERMANENT BARLEY PLOTS—ROTHAMSTED.

Large scale maltings.

Larger bulks of the barleys from Barneyhill, Walcott and Wellingore were malted by the kindness of Messrs. Hugh Baird and Co., Ltd., Glasgow, and Messrs. Gilstrap, Earp and Co., Ltd., Newark; seventy-five quarters of the Barneyhill barley was malted by the former, the bulk being made up from all the plots blended. In the case of the Walcott and Wellingore barleys the grain from each plot was kept separate and malted by itself, the bulks steeped varying from 11 to 17 quarters.

The results of the bulk maltings are set out in Tables VI and VII in comparison with those from the same malts made in bags at Messrs. Fuller, Smith and Turner's maltings at Chiswick.

TABLE V.

Barley from Barneyhill.

			Bulk.	Bag.
Moisture, per cent.	...	...	0.7	2.30
Extract of dry malt	...	...	99.8	98.5
Colour	...	...	5.75	4.0
Diastatic power	...	...	26.0	36.0
Cold water extract, per cent.	...	...	20.9	19.0

TABLE VI.

Barley from Wellingore.

Plot :	1	2	3	4	5
<i>Bulk—</i>					
Moisture, per cent.	1.5	1.2	1.1	1.3	1.1
Extract of dry malt	96.9	98.7	98.7	97.3	99
Colour	6.2	8.7	10.2	6.2	12.7
Diastatic power	46.5	40.0	40.0	50.0	37.0
Cold water extract, per cent.	20.2	20.4	20.6	20.1	20.2

NOTE.—Nos. 2, 3 and 5 were rather scorched on kiln owing to a gale; probably extract has been reduced by 0.5 lb. and the diastase reduced.

<i>Bag—</i>					
Moisture	2.3	2.5	2.5	2.3	2.1
Extract of dry malt	96.2	97.5	97.7	96.9	98.3
Colour	4.7	6.5	4.8	5.3	4.7
Diastatic power	50.0	47.0	48.0	45.0	45.0
Cold water extract, per cent.	21.1	22.0	21.2	22.2	21.6

TABLE VII.
Barley from Walcott.

Plot :	1	2	3	4	5
<i>Bulk—</i>					
Moisture per cent.	1·3	1·1	1·3	1·1	1·3
Extract of dry malt	98·5	97·7	98·0	98·0	97·9
Colour	8·7	9·2	7·2	9·0	7·0
Diastatic power	39·0	38·0	47·0	38·5	40·5
Cold water extract, per cent. .	20·3	19·7	20·5	20·0	20·9
<i>Bag—</i>					
Moisture, per cent.	2·7	2·9	2·7	3·2	2·7
Extract of dry malt	95·3	94·6	94·5	94·5	95·1
Colour	4·2	4·5	5·3	4·3	5·3
Diastatic power	38·5	37·5	37·5	37·5	38·0
Cold water extract, per cent. .	20·6	20·6	21·9	20·6	21·4

In conclusion, it is desired to express the deepest appreciation of the courtesy of Sir E. J. Russell in placing the facilities offered by the Rothamsted Laboratory at the disposal of the Institute. Without these it would have been very difficult to have carried out such an extensive series of analyses. The author also wishes to express his thanks to Mr. H. J. Page and the members of the Scientific and Assistant Staff at Rothamsted for their unvarying kindness and help, and to Messrs. A Hadley, J. M. Lones and R. L. Siau for the loan of valuable apparatus.

Rothamsted Experimental Station.

May, 1924.

ANALYTICAL RESULTS—continued.

No.		Governor and Locality.	Plot.	BARLEY.										MAIZE.										VALUATION.																																																																																																																																																																																																																																																																																																																																																																																																			
				Valuation, shillings per 48 lb.	Moisture per cent.	Sweated barley per cent.	1,000 grain weight dry, grams.	Nitrogen per cent.		Soluble in alcohol, sp. gr. 0.9.	Diastase power on dry barley.	Moisture per cent.	1,000 grain weight dry, grams.	Starch per cent.		Color.	Ther. static power.	Cold water extract, per cent.	Extract.			Nitrogen per cent.	Per-centage on dry malt.		Pro-portion of malt.	Per-centage on dry malt.	Pro-portion of malt.	Per-centage on dry malt.	Pro-portion of malt.	Per-centage on dry malt.	Pro-portion of malt.	Per-centage on dry malt.	Pro-portion of malt.	Per-centage on dry malt.	Pro-portion of malt.	Per-centage on dry malt.	Pro-portion of malt.	Per-centage on dry malt.	Pro-portion of malt.	Per-centage on dry malt.	Pro-portion of malt.	Per-centage on dry malt.	Pro-portion of malt.	Per-centage on dry malt.	Pro-portion of malt.	Per-centage on dry malt.	Pro-portion of malt.	Per-centage on dry malt.	Pro-portion of malt.	Per-centage on dry malt.	Pro-portion of malt.	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BARLEYS GROWN AT NOTHAMSTED

No	Field	Prod	Mature	BARLEYS										MATS.										Close		
				Valuation	Moisture per cent.	Moisture oven-dry per cent.	1,000 corn weight, dry, grams.	Nitrogen per cent.		Soluble in dry alcohol.	Diastatic power per cent.	Moisture per cent.	1,000 corn weight, grams.	Shaken per cent.		In water, 1 lb. 100.	Colour.	Diastatic power.	Cold water extract per cent.	Extract			Nitrogen per cent.			
								On dry.	In water.					Per cent. on dry malt.	Fine ground, 44 lb. dry malt.					Per cent. on dry malt.	In dry malt.	Permanently soluble.				
88	Little Hires	H1	N and protein with slag	4	16.90	9.11	44.4	1.714	—	—	2.72	40.0	30.9	16.4	6.0	28.0	14.3	86.7	80.1	68.7	—	—	—	1.635	—	
89		H2	in 1920	36	17.48	9.35	44.5	1.575	—	—	2.44	40.0	31.5	12.0	5.5	28.0	15.4	90.7	82.9	71.6	—	—	—	1.533	—	
90		H3	1921	40	17.40	9.28	44.4	1.516	—	—	2.22	38.9	18.1	3.3	5.0	32.0	18.9	91.6	86.7	74.6	—	—	—	1.401	—	
91		H4	1919	45	17.47	9.31	46.7	1.508	—	—	2.22	40.0	19.0	5.8	4.5	30.0	17.3	94.0	86.4	74.3	—	—	—	1.481	—	
92		H5	N and K only	45	18.13	9.11	46.2	1.494	—	—	2.32	40.0	9.5	2.2	4.7	36.0	19.7	95.5	87.7	75.3	—	—	—	1.525	—	
Average				42.2	17.38	9.23	45.2	1.533	—	—	2.43	39.9	24.1	7.9	5.1	31.0	17.1	92.3	84.6	72.9	—	—	—	1.530	—	
105	Great Hires	AN81	Nitrate and silicate of soda	45	19.30	13.74	38.4	1.738	—	—	2.56	—	—	—	6.5	24.0	19.4	95.4	97.9	75.5	100.0	—	—	98.5	1.537	0.543
106	"	" 2	Nitrate and silicate of soda + P ₂ O ₅	36	18.14	11.90	41.2	1.571	—	—	2.08	—	—	—	24.0	24.0	30.0	95.1	97.7	75.3	—	—	—	97.3	1.483	—
107	"	" 3	Nitrate and silicate of soda + K ₂ O and Mg	32	20.06	11.28	42.8	1.726	—	—	2.02	—	—	—	12.7	27.5	21.2	94.2	96.7	71.6	98.2	—	—	94.0	1.740	0.643
108	"	" 4	Nitrate and silicate of soda + K ₂ O, Mg and P ₂ O ₅	45	18.70	13.10	41.2	1.430	—	—	2.76	—	—	—	6.7	25.5	21.1	97.4	100.2	77.2	—	—	—	100.1	1.421	—
Average				39.5	—	12.0	41.1	1.621	—	—	2.05	—	—	—	8.0	23.2	20.4	96.5	98.1	75.6	—	—	—	99.1	1.545	—
109	Great Hires	711	Nitrate and silicate of soda	45	19.08	13.57	42.5	1.320	0.286	40.5	2.56	31.1	3.0	0.25	6.5	23.0	21.2	96.2	98.8	76.2	100.0	—	—	99.1	1.278	—
110		712	Permanganate and silicate of soda	30	20.1	14.47	38.4	1.730	0.477	38.0	2.06	30.0	15.2	1.5	8.0	20.0	20.7	93.3	96.2	74.2	100.0	—	—	96.4	1.730	0.617
111		713	Nitrate and silicate of soda + P ₂ O ₅	42	20.16	12.65	37.2	1.200	0.286	28.0	2.32	33.8	3.7	0.6	6.0	22.0	20.9	97.7	100.2	77.2	100.0	—	—	100.0	1.117	—
Average				42	20.27	13.53	39.4	1.457	—	34.0	2.61	34.6	7.3	0.78	6.8	23.0	20.9	95.7	98.1	75.8	101.3	—	—	98.5	1.385	—
118	Long Hires	H1	Control	42	19.35	11.80	41.6	1.613	—	—	2.50	—	—	—	4.7	—	—	96.0	98.5	75.9	—	—	—	—	—	—
119		H2	Control	42	20.20	11.80	40.2	1.610	—	—	2.48	—	—	—	5.0	—	—	96.0	97.7	75.3	—	—	—	—	—	—
120		H3	Control	42	20.28	11.36	39.4	1.602	—	—	2.50	—	—	—	5.5	—	—	95.6	97.8	75.4	—	—	—	—	—	—
121		H4	400 lb. 7% (4, 4) bag	36	19.20	10.30	43.2	1.600	—	—	2.52	—	—	—	6.5	—	—	95.4	97.8	75.3	—	—	—	—	—	—
122		H5	Control	30	19.15	9.88	41.0	1.535	—	—	2.32	—	—	—	6.5	—	—	95.4	97.7	75.3	—	—	—	—	—	—
123		H6	Control	30	19.28	10.57	42.3	1.607	—	—	2.32	—	—	—	6.0	—	—	94.5	96.6	74.5	—	—	—	—	—	—
Average				38	19.33	10.50	41.3	1.618	—	—	2.42	—	—	—	6.0	—	—	95.4	97.7	75.3	—	—	—	—	—	—
124	Long Hires, Top dressing set	1	2 cent. super + 1 S/A	40	18.35	10.17	43.1	1.643	—	—	2.34	36.6	—	—	7.0	29.5	20.8	94.6	96.8	74.7	—	—	—	93.3	1.520	—
125		2	2 cent. super + 2 S/A	36	19.38	10.30	42.7	1.630	—	—	2.40	44.8	—	—	8.5	29.5	20.5	94.8	96.2	73.3	—	—	—	91.3	1.565	—
126		3	2 cent. super only	40	19.12	11.04	44.4	1.610	—	—	2.34	37.1	—	—	8.0	31.0	20.2	94.1	96.2	74.2	—	—	—	93.4	1.562	—
127		4	2 cent. super + 1 M/A	40	19.46	10.40	47.5	1.688	—	—	2.54	37.0	—	—	6.0	31.0	20.4	94.5	96.9	74.7	—	—	—	94.2	1.686	—
Average				39	19.11	10.55	44.4	1.644	—	—	2.38	42.5	—	—	7.1	30.3	20.7	94.0	96.2	74.2	—	—	—	93.0	1.601	—

BARLEYS FROM THE NATIONAL INSTITUTE OF AGRICULTURAL BOTANY, CAMBRIDGE.

No.	Name	Valuation.	BARLEY.			MALT.										
			Moisture. Per cent.	Nitrogen on dry barley. Per cent.	1,000 corn wt. dry barley grams.	Class.	Order of merit.	Moisture per cent.	Extract, lb. per qr.	Extract on dry malt.	Extract, dry, per cent.	Colour.	Nitrogen on dry malt. per cent.	Diastatic Power.	Cold water extract per cent.	pH of hot mash.
		GROWN AT CAMBRIDGE.														
		With Garton 1917 as Control.														
131	Beaven's 1920	Better quality than control.	17.82	1.732	}											
132	Webb's B.	Worth going on with.	18.51	1.780												
133	Golden Pheasant	Not so good as control, usable making barley.	19.17	1.962												
134	Cambridge 59/120	Slightly better than control, but scarcely any difference	18.31	1.853												
		Not so good as control. Not worth going on with.														
		With Archer as Control.														
136	Beaven 1920	Much better than control.	18.62	1.670	}											
137	Webb's B.	Worth going on with.	—	—												
138	Golden Pheasant	Very similar to control. Neither very nice.	18.87	1.915												
		Better than control. Worth going on with.														
		20 lb. bulked samples, sweated.														
131/6	Beaven's 1920		13.02	1.691	40.9	3	1	1.84	94.3	96.0	74.0	6.5	1.635	41.5	18.9	5.6
132/7	Webb's B.		12.43	1.849	38.5	3	4	1.98	94.5	96.4	74.4	5.7	1.801	43.0	19.5	5.6
133/8	Golden Pheasant		12.64	1.936	41.1	3	2	2.00	94.5	96.3	74.3	7.0	1.883	40.0	20.1	5.6
134/9	Cambridge		13.15	1.941	—	—	—	—	—	—	—	—	—	—	—	—
135	Garton, 1917		12.12	1.904	38.4	3	3	1.92	92.1	93.9	72.4	6.0	1.859	41.5	19.3	5.6
140	Archer		12.07	1.825	36.0	3	5	1.80	92.1	93.8	73.3	6.5	1.757	41.5	20.0	5.6
		GROWN AT MARKET WHORTON, YORKS.														
		20 lb. bulked samples (sweated).														
151	Beaven's 1920	Worth going on with	10.59	1.416	41.5	—	1	1.90	96.3	98.2	75.7	5.0	1.296	26.0	18.8	5.6
152	Webb's B.	Not worth going on with. Poorest of the lot.	10.46	1.432	—	—	—	—	—	—	—	—	—	—	—	—
153	Golden Pheasant	Worth going on with	10.60	1.674	42.6	—	2	1.86	95.1	96.9	74.7	5.0	1.550	28.5	19.7	5.6
154	Cambridge	Not good for Yorks.	10.91	1.646	—	—	—	—	—	—	—	—	—	—	—	—
155	Garton's 1917	Poorer than Cambridge	10.42	1.574	36.8	—	3	2.08	91.7	93.7	72.3	5.5	1.494	29.5	18.1	5.55
160	Archer	No good at all for Yorks.	10.38	1.562	36.0	—	4	2.07	93.7	96.5	73.6	5.5	1.516	24.0	19.0	5.6

ANALYTICAL RESULTS—continued.

No.	Name	Valuation.	BARLEY.			MALT.											
			Moisture. Per cent.	Nitrogen on dry barley. Per cent.	1,000 corn wt. dry barley grams.	Class.	Order of merit.	Moisture per cent.	Extract. lb. per qt.	Extract on dry malt.	Extract, dry, per cent.	Colour.	Nitrogen on dry malt per cent.	Diastatic Power.	Cold water extract, per cent.	pH of hot mash.	
		GROWN AT NEWPORT, SALOP.															
		With Garton's 1917 as Control.															
161	Beaven's 1920	Better than control. Worth going on with.	19.36	1.601	} Not malted.												
162	Webb's B.	Very like control. Worth going on with.	18.17	1.556													
163	Golden Pheasant	Better than control. Worth going on with.	18.26	1.835													
164	Cambridge	Rather poor. Not worth going on with.	—	—													
165	Garton's 1917	Not satisfied with this. Not worth going on with.	—	—													
166	Archer	Not satisfied with this. Not worth going on with.	—	—													
		20 lb. bulked samples.															
171	Beaven's 1920		12.78	1.600	45.0	—	1	2.00	98.6	98.6	76.0	6.0	—	38	19.4	5.6	
172	Webb's B.		12.12	1.680	43.7	—	4	1.94	94.2	96.1	74.1	6.5	—	37	19.7	5.6	
173	Golden Pheasant		12.98	1.764	44.6	—	2	2.16	94.6	96.7	74.6	7.5	—	32	19.6	5.65	
174	Cambridge		12.14	1.789	—	—	—	—	—	—	—	—	—	—	—	—	
175	Garton's 1917		12.16	1.629	43.0	—	3	2.00	92.7	94.6	72.9	6.5	—	37	19.5	5.55	
176	Archer		12.78	1.756	43.1	—	5	2.00	90.7	92.5	71.3	6.0	—	36	19.3	5.65	

ANALYTICAL RESULTS

Plots numbered to correspond with the different manurial treatments as follows:—(1) No manure. (2) Complete artificial. (3) No potash. (4) No phosphate. (5) No nitrogen.

No.	Ground and Locality.	Plot	BARLEY.										MAIZ.										VALUATION.			
			Valuation Stalkings per 48 lb.	Moisture per cent.	Sweated barley moisture per cent.	1,000 corn weight/dry barley grams	Nitrogen per cent.		Diastatic power on dry barley	Moisture per cent.	1,000 corn weight dry grams.	Stalks per cent.		Diastatic power.	Cold water extract per cent.	Extract.		Nitrogen per cent.		p of hot mash.	Class.	Remarks and average value.				
							On dry barley.	Soluble in alcohol, up gr. 0.9				In water.	In 100 cc. up gr. 1.50.			Colour.	Lb. per qr. on dry malt.	Lb. per qr. on dry malt fine ground.	Per cent. on dry malt.				Lb. per qr. on 48 lb dry barley.	Per- manently soluble on dry malt.		
(Original Seed)	—	—	11.20	44.8	1.307	0.429	21.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—					
1	St H Hope, Barnetall, & Latham	1	48	16.81	13.00	47.4	1.302	—	29.5	2.82	42.9	19.8	0.5	4.2	37.0	18.3	96.4	99.2	—	76.5	100.2	1.480	—	5.75	1	Very level lot
2		2	48	15.08	13.01	46.6	1.300	—	27.0	2.30	42.6	11.6	0.1	3.7	35.0	18.0	97.9	100.4	102.2	77.4	102.3	1.378	0.404	5.75	1	
3		3	48	15.83	14.88	46.2	1.470	—	27.5	2.78	43.6	24.0	0.0	4.0	37.0	18.7	96.2	99.0	101.6	76.3	102.4	1.481	0.401	5.75	1	
4		4	48	16.07	14.08	45.9	1.500	—	29.0	2.64	44.4	22.0	0.9	4.0	36.0	18.5	95.7	98.3	100.8	75.8	100.7	1.485	0.510	5.75	2	
5		5	53	16.40	11.44	46.1	1.384	—	27.5	2.48	41.0	30.5	0.5	4.0	35.0	18.6	95.7	98.1	100.5	75.6	101.0	1.508	0.483	5.75	1	
6		6	48	16.21	11.68	45.1	1.419	—	28.0	2.32	43.0	31.0	0.2	3.7	35.0	18.9	98.1	100.4	101.4	77.4	100.8	1.369	0.460	5.75	1	
7		7	48	16.21	11.68	45.1	1.419	—	28.0	2.48	41.7	33.6	0.7	3.7	36.0	18.9	96.3	98.8	—	76.2	99.8	1.475	0.462	5.75	2	
8		8	55	—	11.34	44.9	1.505	—	—	2.30	43.8	15.8	0.9	4.0	36.0	19.0	96.2	98.5	—	75.9	98.8	1.416	—	5.75	1	
	Average (2 to 6)		48.4	15.06	13.07	46.4	1.437	0.42	27.5	2.60	43.5	23.8	0.5	3.9	36.0	18.5	96.7	99.2	101.3	76.5	101.6	1.446	0.487	5.75	1.2	78 1/2
9	W Haker, Dunrobin, Essex	1	42	19.44	13.00	38.6	1.748	—	—	2.20	36.0	14.8	0.3	4.0	41.0	19.6	95.4	97.5	—	75.2	96.9	1.719	—	5.75	3	Medium, level lot
10		2	42	18.29	14.50	41.0	1.751	—	—	2.34	37.9	14.7	0.3	4.2	41.5	19.9	94.1	98.3	—	74.2	97.0	1.741	0.642	5.75	3	
11		3	42	17.85	12.70	40.5	1.650	—	—	2.10	36.5	15.6	0.7	4.2	41.5	19.2	93.0	95.0	—	73.7	94.2	1.778	—	5.75	3	Order of value- ton, 9, 10, 11 & 12, 13
12		4	42	17.89	13.35	37.7	1.748	—	—	2.44	40.0	27.5	0.25	4.0	41.0	20.0	94.6	96.9	—	74.7	96.6	1.758	0.610	5.75	3	
13		5	42	18.00	14.77	40.3	1.775	—	—	2.70	37.3	30.0	2.4	1.0	11.5	18.4	91.6	94.1	—	72.6	95.5	1.765	—	5.75	4	
	Average		42	18.35	13.42	39.6	1.774	0.51	38.5	2.35	38.1	20.5	0.8	4.1	41.3	19.4	93.9	96.1	99.0	74.1	96.0	1.732	0.630	5.75	3.2	62 1/2
14	A R Dorr, Cockfield, Surrey	1	28	19.24	12.07	36.8	1.500	—	37.5	2.08	35.4	3.6	0.3	4.0	41.5	18.0	95.6	97.7	98.8	75.3	98.0	1.406	0.465	5.75	3	Quite good malt from poor barley
15		2	30	18.51	13.43	38.3	1.565	—	36.5	2.25	35.9	5.5	Nd	3.7	40.5	17.6	94.6	96.8	97.8	74.0	97.5	1.472	0.515	5.75	3	
16		3	30	18.95	12.20	36.6	1.496	—	36.5	2.24	35.7	4.2	0.14	3.7	41.5	17.8	95.7	97.9	99.2	75.5	97.9	1.420	0.429	5.75	3	
17		4	30	18.67	12.24	41.7	1.494	—	34.5	2.26	33.5	3.4	Nd	3.7	38.0	19.1	95.8	98.1	—	75.6	97.4	1.431	—	5.75	3	
18		5	30	20.21	12.42	39.9	1.490	—	35.5	2.34	36.2	4.1	0.15	3.7	38.0	18.5	96.9	99.2	—	76.5	98.6	1.448	—	5.75	3	
	Average		29.5	19.11	12.57	38.7	1.526	0.42	36.0	2.25	35.5	4.2	0.12	3.75	40.0	18.2	95.7	97.9	98.6	75.5	97.9	1.447	0.513	—	3	64
19	G B Noble, Wellmar, Lancs	1	36	18.89	12.57	40.7	1.759	—	—	2.35	38.4	15.0	2.2	4.7	39.0	21.1	93.9	96.2	—	74.2	94.8	1.778	—	5.7	4	Appearance of Class 3 Extract
20		2	36	17.70	12.37	41.9	1.804	—	—	2.55	37.2	11.2	1.0	6.5	47.0	22.0	94.9	97.5	—	75.2	97.0	1.752	—	5.7	4	
21		3	36	17.70	12.38	43.3	1.762	—	—	2.54	37.7	11.2	0.6	4.8	48.0	21.2	95.3	97.7	—	75.3	97.3	1.772	—	5.65	4	
22		4	32	18.60	11.90	44.6	1.835	—	—	2.36	36.5	13.2	1.0	5.3	46.0	22.2	94.6	96.9	—	74.7	95.0	1.856	—	5.7	4	Buts were bet- ter appearance.
23		5	40	18.13	13.10	41.9	1.720	—	—	2.10	36.8	13.1	1.0	4.7	48.0	21.6	96.3	98.3	—	75.8	95.8	1.703	—	5.7	4	
	Average		36	18.24	12.24	42.5	1.790	0.49	39.5	2.38	37.7	12.7	1.2	5.2	47.8	21.6	95.0	97.3	99.4	75.0	96.0	1.772	0.617	—	4	55 1/2

ANALYTICAL RESULTS—continued.

No.	Grower and Locality.	Plot.	Bazzy.										Misc.										Variation.			
			Volatiles, Shilling per 44 lb.	Moisture per cent.	Sweated barley moisture, per cent.	1,000 corn weight dry barley, grams.	Nitrogen per cent.		Distillate power on dry barley.	Moisture per cent.	1,000 corn weight dry, grams.	Starches per cent.			Dis- tate power.	Cold water extract per cent.	Extract.				Nitrogen per cent.		p _h of hot mash.	Chow.	Remarks and average value.	
							On dry barley.	Soluble in alcohol sp. gr. 0.9				In water.	In lime sp. gr. 1.150.	Colour.			Lb. per qr.	Lb. per qr. on dry malt.	Lb. per qr. on dry malt fine ground.	Per cent. on dry malt.	Lb. per qr. on 44 lb dry barley.	On dry malt.				Per manurely soluble on dry malt.
24	P. Ong Thaw.	1	32	17.71	13.30	47.3	1.857	—	—	2.26	44.3	35.5	1.4	5.0	43.5	19.6	92.7	94.9	—	73.2	94.8	1.927	—	5.75	4	
25	Estim-on-Sewen.	2	32	18.46	13.60	48.0	1.890	—	—	2.48	44.3	36.0	0.2	6.0	46.0	20.1	93.0	95.4	—	73.6	95.1	1.930	—	5.5	4	
26	Ship	3	32	17.07	13.53	47.0	2.009	—	—	2.60	42.5	33.2	1.5	8.0	49.0	20.0	91.9	94.4	—	72.8	93.6	2.067	—	5.8	4	Worst
27		1	40	17.74	13.23	46.8	1.867	—	—	2.50	44.8	32.3	1.3	5.5	44.5	20.6	94.6	95.8	—	73.9	97.0	1.930	0.008	5.8	4	Second.
28		3	40	17.46	13.46	48.2	1.869	—	—	2.04	44.6	38.2	0.4	5.8	42.0	19.6	91.1	96.0	—	74.0	96.0	1.957	0.020	5.75	4	Best.
	Average	—	35.2	17.87	13.44	47.3	1.922	0.02	40.0	2.38	44.1	35.0	1.0	6.1	45.0	20.6	93.3	95.3	97.3	73.5	95.4	1.928	0.014	—	4	55
29	W. H. Edwards.	1	45	17.00	13.73	41.8	1.528	—	—	2.26	40.6	10.0	0.5	3.7	36.0	19.5	96.0	98.2	—	74.0	98.6	1.534	—	5.8	13	Order of merit.
30	Miverton.	super only	48	17.00	13.27	13.3	1.642	—	—	2.32	39.8	10.3	0.6	4.2	37.0	20.3	96.0	98.2	—	74.0	98.1	1.566	—	5.75	2	20, 31, 30.
31	Sunset	3	55	17.13	14.00	42.3	1.478	—	—	2.48	39.4	8.0	0.8	4.0	37.0	20.7	96.2	98.7	—	74.2	99.8	1.490	—	5.8	13	
	Average	—	49.3	17.47	13.99	42.4	1.549	0.40	40.5	2.35	39.9	9.4	0.6	4.0	36.6	20.2	96.1	98.4	—	74.1	98.8	1.530	0.528	—	1.33	77.46.
32	E. G. Freeman.	1	65	18.08	14.36	42.7	1.428	0.361	41.0	2.26	38.8	1.5	0.7	1.5	36.0	22.5	97.6	99.9	101.4	77.0	101.1	1.442	0.544	—	1	Very level lot.
33	Orwell Park.	2	65	16.74	14.08	43.8	1.529	0.355	39.5	2.46	39.1	2.1	0.4	4.2	36.0	21.9	97.4	99.9	101.7	77.0	100.3	1.420	—	—	1	
34	Murlesham.	3	64	16.48	14.23	43.6	1.530	0.369	37.5	2.42	38.5	3.8	0.5	4.0	36.0	22.3	97.0	99.4	—	76.6	99.8	1.479	—	—	1	
35	Subak.	4	64	17.98	13.67	43.3	1.555	0.400	40.5	2.44	38.9	4.1	0.5	4.0	37.0	21.8	97.6	100.0	100.6	77.1	99.7	1.430	0.536	5.65	1	
36		5	60	16.50	13.68	42.3	1.516	0.361	39.5	2.36	38.6	3.9	0.3	4.0	37.0	22.0	97.4	99.8	—	76.9	99.8	1.454	—	5.65	1	
37	Lila chad seed.	57	18.85	13.05	42.7	1.508	0.412	36.0	2.42	38.8	4.3	0.6	5.0	34.0	20.8	96.9	99.7	—	76.8	98.7	1.529	—	5.65	2		
	Average (32-37)		63.6	17.16	13.68	42.9	1.511	0.39	39.5	2.30	38.8	3.7	0.5	4.1	37.2	22.1	97.7	99.8	101.2	76.9	100.2	1.447	0.540	—	1	89.
38	C. Bambridge.	1	30	16.45	14.01	36.2	1.698	—	—	2.68	34.4	4.8	0.8	4.2	38.5	20.6	92.7	95.3	—	73.5	95.8	1.670	—	5.75	4	Had hard malt
39	Wald.	2	30	17.25	15.57	34.2	1.881	—	—	2.92	32.6	5.2	0.5	4.5	37.5	20.6	91.9	94.6	—	72.9	95.8	1.833	—	5.7	1	but far extract.
40	Lanes	3	30	17.39	15.49	33.8	1.791	—	—	2.68	32.8	7.6	0.4	5.3	37.5	21.9	91.9	94.5	—	72.8	94.9	1.857	—	5.7	5	
41		4	30	20.06	16.02	35.7	1.978	—	—	3.26	33.3	10.4	0.1	4.3	37.5	20.6	91.4	94.5	—	72.8	97.2	1.856	—	5.75	4	
42		5	30	17.67	16.41	36.3	1.722	—	—	2.68	34.2	5.6	0.5	5.3	38.0	21.4	92.7	95.1	—	73.3	96.3	1.742	—	5.7	4	
	Average	—	30	17.70	15.80	35.2	1.794	0.50	39.5	2.84	33.5	6.7	0.5	4.7	37.8	21.0	92.1	94.8	97.6	73.1	96.0	1.792	0.622	—	4.2	53.46.
43	P. Hill.	1	31	16.58	11.90	41.2	1.623	—	—	2.38	36.6	12.0	0.3	4.5	39.0	20.2	94.2	96.5	—	74.4	95.0	1.612	—	5.8	3	Very useful malt
44	Drehan.	2	31	16.71	10.65	43.9	1.667	—	—	2.68	37.0	13.2	Nd	4.5	45.0	20.5	94.2	96.8	—	74.6	93.7	1.706	—	5.7	3	ale malt from
45	Stork.	3	31	16.66	11.86	43.2	1.617	—	—	2.36	37.3	7.9	0.15	4.5	41.0	20.6	94.7	97.0	—	74.8	94.6	1.647	—	5.8	3	poor looking for-
46		4	31	16.94	12.12	42.4	1.687	—	—	2.34	40.0	12.0	0.5	5.5	41.0	21.0	95.7	98.0	—	75.6	97.0	1.680	—	5.7	3	lery, best 43, 46 &
47		5	31	16.25	12.25	41.9	1.662	—	—	2.62	39.0	8.7	Nd	5.5	39.0	20.5	95.3	97.7	—	75.4	96.7	1.629	—	5.7	3	17, next 44 & 45.
	Average	—	31	16.83	11.76	42.5	1.651	0.47	39.0	2.46	36.6	10.8	0.2	4.9	42.0	20.6	94.8	97.2	100.0	75.0	95.1	1.650	—	—	3	64

THE INSTITUTE OF BREWING RESEARCH SCHEME.

SECOND REPORT ON THE INFLUENCE OF SOIL, SEASON AND MANURING ON THE QUALITY AND GROWTH OF BARLEY, AS INDICATED BY THE MALTS MADE THEREFROM.

By H. M. LANCASTER.

SIR JOHN RUSSELL has given details of the 1923 Centres in his second report—(this Journ., 1924, 30, 818-819.)

The malting process was carried out in exactly the same way as last year, four samples of each barley being taken. This year, however, the malt moistures were taken on the *average* of each four samples and the malting loss calculated on the aggregate of four maltings of each lot which were carried out in excellent weather between January and the end of March, 1924. All the analytical work has been done as last year by Mr. Lloyd Hind, and the results are embodied in a separate appendix, only the malt extracts (calculated on dry matter) being given in the first appendix.

Last year an average moisture content of 17.4 per cent. was assumed for all barleys, but this year the actual moisture content of each sample was taken. As moisture content varied between 19.4 in barley from Beverley and 15.1 in barley from Lincoln Heath, this method obviously furnishes a truer index of the value of each lot.

With regard to malting loss, no account has been taken of possible loss of dry matter during artificial sweating, so that the malting losses shown in col. 2 are probably rather too low. They are, however, fairly comparable *inter se*, as between the different lots from each station.

The object of this report is to assess, as fairly as possible, the value of each lot of barley from the resultant malt, and, if we call this the "actual value," for this season only, the following deductions are drawn :—

- (1) Other things being as far as possible equal, *different manurial treatments* made practically no difference to the market value of the barley, or to the actual value of the barleys as judged by the resultant malts, both market value and actual value coming out very closely for each individual station.
- (2) Soil and season were obviously predominant in determining both market value and actual value.

These two deductions confirm last season's results.

- (3) With regard to *value per acre*, different manurial treatments have resulted in the actual values per acre given below.

The following table gives average results for eight stations for the 1922 crop and 11 stations for the 1923 crop :—

—	1922.		1923.	
	Value per acre.	Per cent. of Maximum value.	Value per acre.	Per cent. of Maximum value.
Complete Manure	Shillings. 237	Per cent. 97	Shillings. 234	Per cent. 100
„ „ less K	222	91	229	98.2
„ „ „ P	244	100	226	96.6
„ „ „ N	215	88	193	82.5
No manure	222	91	192	82.5

The stations taken above are :—

For 1922 harvest :—Barneyhill ; Dunmow ; Louth ; Wellngore ; Eyton-on-Severn ; Nacton ; Walcott ; Dereham.

And for 1923 harvest :—Barneyhill ; Louth ; Wellngore ; Eyton-on-Severn ; Chiselborough ; Nacton ; Walcott ; Dereham ; Beverley ; Newport, Salop ; Rothamsted.

The Woburn barleys were unfortunately heated, the Warminster barleys were not strictly comparable in the manures used, and those from Dunmow by an unfortunate mistake were from a different strain of seed barley from the others.

It is most interesting to note that, in addition to the five barleys grown at Rothamsted, two others were grown in which Muriate of Potash

and Muriate of Ammonia were used instead of the Sulphates. Both in market value, in actual value, and in actual value per acre, these two barleys came out best at their station.

Market Value of Barley and Actual Value as indicated by Malt.

The Committee's valuation of the *barleys* may be taken as a correct interpretation of the market value at the time of valuation.

Their valuation of the *malts* depends upon their market value—

Judged by—Appearance.
Palate.
Extract.

This valuation is the main factor in the determination of the "*Actual Value of 448 lb. raw barley dressed*" in column 8.

Other factors being:—

Moisture content of Barley.
Malting loss.

In cases of—

Wellingore,
Eyton-on-Severn,
Warminster, Wilts,
Beverley, Yorks, and
Rothamsted,

the market values and actual values were very fairly close.

In those of—

Nacton,
Dereham,
Walcott,
Newport, Salop,

the barley was not considered such as would have been bought for malting and the malts bore this out.

The Barneyhill barley was overvalued by about 10 per cent., and the Chiselborough barley was undervalued by no less than 10s. per qr., or over 20 per cent.

The barley from the Lincoln wolds was undervalued by 12 per cent., or about 5s. per qr., and it is rather remarkable that last year this barley was undervalued by over 10s. per qr.

The malts may be roughly divided into—

Fine.—Chiselborough, Warminster, Rothamsted, Wellingore, Eyton-on-Severn.

Good.—Barneyhill, Louth, Beverley.

Poor.—Walcott, Newport.

V. Poor.—Nacton, Dereham,

and if the average of actual value of barley nitrogen content, and malting loss on these is taken, we obtain the following figures:—

—	Fine.	Good.	Poor.	V. Poor.
Value ...	53s.	44s.	36s.	30s.
Malting loss	7.7%	6.8%	8.0%	9.0%
Nitrogen	1.54%	1.51%	1.72%	1.96%
Extract per 336 lb. malt with 2% moisture.	99.0	97.5	95.0	93.0

Rothamsted Barleys.

Nos. 93, 94, 95, 96 are the No Nitrogen series on the Hoos Field. They give wretched yields. No. 94 with Superphosphate and No. 96 with full minerals less N. gave excellent barleys and malts.

No. 100 with full minerals and Sulphate of Ammonia, and No. 104 with full minerals and nitrate of soda also gave fine barleys and malts with fair yields, as did Nos. 108 and 116 (full minerals and rape cake), which gave one of the best barleys and malts of the series, very nearly the highest yield per acre and actually the highest value per acre (£11 12s.). All these barleys except Nos. 117, 125 and 130 are from the Hoos Field, which has been growing barley since 1852.

If the Chemical Sub-Committee intend to carry out any further investigations on barleys or malts, those which seem most likely to furnish information are:—

- (1) Nos. 14, 15, 16, 17, 18.

These were very substantially undervalued as barley, and were also undervalued as barley last year.

- (2) No. 27.

This was rather a high nitrogen barley which made very good malt.

- (3) Nos. 29, 30, 31, 31A and 31B, where again the market value was much lower than the actual value, and also because they made the best malts.

- (4) Rothamsted Nos. 86 and 87, where the Muriates used instead of Sulphates apparently increased the yield substantially and also slightly improved the quality both of barley and malt,

and also Nos. 108 and 116, where rape cake seems to have given very good results.

With reference to the Appendix, as it is extremely difficult to describe the manuring of "Other Rothamsted barleys," an explanatory diagram of the Hoos Field is given below, by kind permission of Sir John Russell. In this

the plots are numbered, as in the Appendix, and the full description of manures used is given laterally and horizontally. The lateral descriptions of manuring in O and A do not, of course, apply to Nos. 109, 110, 111 and 112. Nos. 105, 106, 107 and 108 are manured similarly to Nos. 101, 102, 103 and 104, with the addition of silicate of soda.

HOOS FIELD.

BARLEY SINCE 1852.

		116	115	114	113	C Rape Cake 1000 lb. per acre. (49 lb. N.)
		108	107	106	105	AAS Same as AA with Silicate of Soda.
		104	103	102	101	AA Nitrate of Soda 275 lb. per acre. (43 lb. N.)
110 Farm Yard Dung 14 tons per acre.	111 Coal Ashes only.	100	99	98	97	A Sulph. Amm. 206 lb. per acre. (43 lb. N.)
109 Dung 14 tons per acre 1852-'71. Since then unmanured.	112 No Manure.	96	95	94	93	O No Nitrogen.
		4 Minerals 3½ cwt. super. 200 lb. S/Pot. 100 " S/Soda. 100 " S/Mag. per acre.	3 Minerals as 4 without super.	2 Super only 3½ cwt. per acre.	1 No Minerals.	

No. 117. Nitrate of soda only.

No. 125. Superphosphate and Sulphate of Ammonia. } Top dressing set.

No. 130. Superphosphate and Urea.

No.	Manurial Dressings.	(1)	(2)	(3) (4)		(5)	(6)	(7)	(8)	(9)
		Sub-Committee's Estimate of Market Value in Jan., 1924.	M'L as % of Dry Matter.	per 336 Dry Malt.	per 448 Raw Barley.	Sub-Committee's Estimate of Market Value of Malt in Jan., 1924.	Bushels Yield per Acre.	Return from Tail Corn per acre : all tail at 30s.	Actual Value of 448 lb. Raw Barley Dressed.	Actual Value per Acre (pence excluded).

SIR HARRY HOPE, M.P., Barneyhill, East Lothian, N.B.

(Soil : *Trias.*)

		<i>s.</i>	<i>d.</i>			<i>s.</i>	<i>d.</i>		<i>s.</i>	<i>d.</i>		<i>s.</i>	<i>d.</i>		<i>s.</i>	<i>d.</i>
2	Unmanured	50	0	6.6	99.6	104.1	70	0	63.0	---	48	0	378	0		
3	Complete manures	49	6	7.7	98.8	101.7	70	0	72.0	---	47	6	427	0		
4	Without potash	49	6	7.5	97.3	100.2	65	0	68.5	---	42	6	364	0		
5	Without phosphates	49	0	7.9	98.0	100.3	65	0	73.0	---	42	0	383	0		
6	Without nitrogen ...	49	0	7.0	98.3	101.7	65	0	71.0	---	42	3	375	0		

A. E. DAVY, Louth, Lincs.

(Soil : *Light Loam—(Chalk.)*)

14	Unmanured ...	41	6	6.2	101.4	102.9	70	0	40.0	+ 2	0	46	9	236	0
15	Complete manures .	42	0	6.5	101.8	103.3	70	0	43.3	+ 3	0	46	9	256	0
16	Without potash .	41	6	6.5	100.8	102.2	70	0	44.8	+ 2	0	46	9	262	0
17	Without phosphates	41	0	6.5	100.4	101.2	70	0	42.8	+ 4	0	46	6	253	0
18	Without nitrogen .	41	6	6.0	100.7	101.7	70	0	35.0	+ 2	0	46	3	204	0

G. H. NEVILE, Wellingore, Lincs.

(Soil : *Oolite.*)

19	Unmanured	52	0	6.8	101.7	107.0	75	0	40.8	+12	0	53	9	286	0
20	Complete manures ..	52	0	7.7	101.8	105.9	75	0	45.8	+12	0	53	0	314	0
21	Without potash	53	0	8.3	101.1	104.1	75	0	43.8	+10	0	52	9	298	0
22	Without phosphates	52	0	8.1	101.4	105.6	75	0	46.4	+10	0	53	0	317	0
23	Without nitrogen	53	0	8.1	101.6	105.8	75	0	39.2	+12	0	53	0	272	0

E. CRAIG TANNER, Eytton-on-Severn, Salop.

(Soil : *Loam.*)

24	Unmanured	48	0	8.8	98.1	102.9	65	0	33.1	+ 5	0	41	6	177	0
25	Complete manures	49	0	7.5	100.7	103.0	75	0	47.3	+ 9	0	52	6	319	0
26	Without potash	49	0	7.1	100.0	103.1	75	0	47.6	+12	0	52	6	324	0
27	Without phosphates	49	0	8.8	100.1	101.9	75	0	44.4	+10	0	52	0	299	0
28	Without nitrogen	50	0	7.5	101.8	101.6	77	0	40.0	+ 4	0	54	6	276	0

C. J. CLARKE, Chiselborough, Somerset.

(Soil : *Inferior Oolite.*)

29	Unmanured	47	0	6.9	100.9	102.9	80	0	27.0	+ 6	0	57	0	199	0
30	Complete manures	47	0	7.2	101.2	103.0	80	0	29.0	+ 8	0	57	0	215	0
31	Without potash	47	0	6.8	100.8	103.1	80	0	26.2	+ 8	0	57	0	195	0
31A	Without phosphates	47	0	7.0	99.8	101.9	80	0	27.0	+ 4	0	57	0	196	0
31B	Without nitrogen ...	46	0	7.5	100.0	101.6	80	0	19.5	+ 7	0	57	0	146	0

No.	Manurial Dressings.	(1) Sub-Com- mittee's Estimate of Market Value in Jan., 1924.	(2) M L as % of Dry Matter.	(3) (4) Brewers' Extract.		(5) Sub-Com- mittee's Estimate of Market Value of Malt in Jan., 1924.	(6) Bushels per Acre.	(7) Return from Tail Corn per Acre : all tail at 30s.	(8) Actual Value of 448 lb. Raw Barley Dressed.	(9) Actual Value per Acre (pence excluded).
				per 336 Dry Malt.	per 448 Raw Barley.					

THE RT. HON. E. G. PRETYMAN, M.P., Nacton, Suffolk.
(Soil : Sand.)

		<i>s. d.</i>				<i>s. d.</i>		<i>s. d.</i>	<i>s. d.</i>	<i>s. d.</i>
32	Unmanured	40 0	10.2	94.1	93.8	55 0	7.8	+3 0	30 6	33 0
33	Complete manures	40 0	10.2	96.0	96.1	55 0	10.8	+3 0	30 9	44 0
34	Without potash	40 0	9.8	95.3	96.2	55 0	5.5	+3 0	31 0	24 0
35	Without phosphates	40 0	10.3	93.5	93.0	55 0	11.2	+3 0	30 9	46 0
36	Without nitrogen	40 0	10.2	93.5	92.9	55 0	8.1	+3 0	30 9	34 0

C. BEMBRIDGE, Walcott, Lincs.
(Soil : Fen.)

		<i>s. d.</i>				<i>s. d.</i>		<i>s. d.</i>	<i>s. d.</i>	<i>s. d.</i>
38	Unmanured	41 6	8.4	96.2	98.2	60 0	50.3	+28 0	36 0	254 0
39	Complete manures	41 6	9.2	97.5	99.5	60 0	48.8	+27 0	36 0	247 0
40	Without potash	41 6	8.6	95.5	96.6	60 0	50.0	+38 0	36 0	263 0
41	Without phosphates	42 0	8.0	97.3	98.4	60 0	47.5	+30 0	36 0	244 0
42	Without nitrogen	41 0	8.5	97.3	97.2	60 0	44.1	+26 0	35 9	223 0

B. HILL, Dereham, Norfolk.
(Soil : Sand, Chalk.)

		<i>s. d.</i>				<i>s. d.</i>		<i>s. d.</i>	<i>s. d.</i>	<i>s. d.</i>
43	Unmanured	39 6	9.4	95.7	94.7	55 0	21.5	+8 0	30 3	89 0
44	Complete manures	40 0	9.2	94.9	93.9	55 0	26.5	+10 0	30 3	110 0
45	Without potash	40 0	9.1	94.9	93.9	55 0	20.8	+5 0	30 3	84 0
46	Without phosphates	40 0	10.2	95.4	92.5	55 0	22.0	+5 0	29 9	87 0
47	Without nitrogen	40 0	9.9	96.5	95.1	55 0	20.4	+6 0	30 0	82 0

J. H. SPILMAN, Beverley, Yorks.
(Soil : Loam over Chalk.)

		<i>s. d.</i>				<i>s. d.</i>		<i>s. d.</i>	<i>s. d.</i>	<i>s. d.</i>
48	Unmanured	43 0	6.9	99.9	100.1	65 0	36.8	9 0	41 0	198 0
49	Complete manures	41 0	8.0	99.3	98.3	65 0	50.3	12 0	40 6	267 0
50	Without potash	43 0	7.0	98.8	99.2	65 0	54.8	14 0	41 0	295 0
51	Without phosphates	43 0	6.7	98.4	99.6	65 0	46.6	12 0	41 3	253 0
52	Without nitrogen	43 0	6.4	99.0	99.4	65 0	38.6	11 0	40 9	207 0

HARPER-ADAMS AGRICULTURAL COLLEGE, Newport, Salop.
(Soil : Lower Trias.)

		<i>s. d.</i>				<i>s. d.</i>		<i>s. d.</i>	<i>s. d.</i>	<i>s. d.</i>
53	Unmanured	42 0	7.2	98.2	98.9	60 0	22.0	24 0	36 0	123 0
54	Complete manures	42 0	6.5	97.4	98.4	60 0	30.6	28 0	36 0	163 0
55	Without potash	42 0	8.0	96.9	96.7	60 0	33.7	30 0	35 9	180 0
56	Without phosphates	42 0	7.2	97.7	98.7	60 0	30.2	30 0	36 0	167 0
57	Without nitrogen	42 0	8.1	97.4	98.4	60 0	33.8	27 0	36 0	179 0

WOBURN EXPERIMENTAL FARM, Apsley Guise, Beds.
(Soil : Lower Greensand.)

		<i>s. d.</i>				<i>s. d.</i>		<i>s. d.</i>	<i>s. d.</i>	<i>s. d.</i>
68	Unmanured	43 0	7.7	95.0	94.9	55 0	33.6	1 0	30 6	129 0
69	Complete manures	56 0	6.5	94.7	97.1	55 0	43.1	1 0	31 3	169 0
70	Without Potash	56 0	5.8	91.2	94.6	55 0	40.6	1 0	31 9	162 0
71	Without phosphates	57 0	7.5	96.4	98.5	55 0	38.1	1 0	31 3	150 0
72	Without nitrogen	58 0	5.6	95.2	97.3	55 0	30.5	—	31 3	118 0

No.	Manurial Dressings.	(1) Sub-Com- mittee's Estimate of Market Value in Jan., 1924.	(2) M/L as % of Dry Matter.	(4) Brewers' Extract.		(5) Sub-Com- mittee's Estimate of Market Value of Malt in Jan., 1924.	(6) Yield. Bushels per Acre.	(7) Return from Tail Corn per Acre. All tail at 30s.	(8) Actual Value of 448 lb. Raw Barley Dressed.	(9) Actual Value per Acre (pence excluded).
				per 336 Dry Malt.	per 448 Raw Barley.					

DR. E. S. BEAVEN, Warminster, Wilts.

(Soil : Greensand.)

		s.	d.			s.	d.			s.	d.			s.	d.
75	Unmanured ...	52	0	7·7	101·5	103·0	73	0	36·7	—	52	0	238	0	
76	Complete manures....	52	0	7·2	102·4	103·7	75	0	43·1	—	52	3	282	0	
77	Without nitrogen .	52	0	8·1	102·6	103·7	75	0	35·4	—	51	9	229	0	
78	Without potash .	52	0	8·3	101·8	102·7	75	0	42·3	—	51	6	272	0	
79	Nitrogen only ...	52	0	7·9	101·7	102·4	75	0	—	—	51	9	—		
80	Unmanured .	51	0	8·4	100·9	101·7	75	0	32·0	—	51	6	206	0	

ROTHAMSTED EXPERIMENTAL STATION, Harpenden, Herts.

(Soil : Clay over Chalk.)

81	Unmanured ...	56	0	8·7	99·3	100·9	75	0	21·4	5	0	52	0	144	0
82	Complete manure .	57	0	8·5	101·0	102·3	75	0	32·8	5	0	51	9	222	0
83	Without potash ...	57	0	6·8	101·2	103·4	77	0	33·9	5	0	54	0	234	0
84	Without phosphates	57	0	6·4	101·0	103·4	77	0	33·8	6	0	54	6	236	0
85	Without nitrogen ...	56	0	7·7	98·4	100·5	75	0	19·5	4	0	52	0	131	0
86	as 83 + M/Potash ...	58	0	8·0	101·9	104·6	77	0	37·3	6	0	54	6	260	0
87	as 85 + M/Ammonia.	58	0	7·9	101·2	103·8	77	0	35·7	6	0	54	6	250	0

OTHER ROTHAMSTED BARLEYS.

93	For manures Nos. 93—130, refer to plan on page 106.	43·0	5·2	94·4	96·7	55	0	10·1	5	0	31	6	45	0
94		54·0	7·0	98·5	101·8	77	0	19·6	4	0	54	6	136	0
95		43·0	8·0	98·2	98·1	60	0	12·0	3	0	35	9	57	0
96		43·0	7·3	100·2	102·2	75	0	16·0	4	0	51	9	108	0
97		49·0	7·7	95·9	98·2	55	0	13·0	9	0	31	6	60	0
98					Not malted.									
99		48·0	8·2	95·5	97·7	55	0	16·0	10	0	31	6	73	0
100		56·0	7·0	100·8	105·3	75	0	33·0	7	0	53	6	227	0
104		50·0	6·9	99·9	104·0	75	0	31·0	7	0	53	0	212	0
105		41·6	7·7	96·1	99·0	60	0	21·0	9	0	36	9	105	0
106		50·0	7·5	100·2	103·4	70	0	35·0	6	0	47	3	211	0
107		41·6	6·9	97·5	100·5	60	0	22·6	6	0	36	9	110	0
108		56·0	7·8	99·8	102·3	70	0	36·0	6	0	47	0	217	0
109		46·0	7·2	99·7	102·5	70	0	17·3	5	0	47	0	107	0
110		50·0	7·5	98·6	102·0	70	0	30·6	5	0	47	6	186	0
111		44·0	8·0	98·5	100·4	60	0	10·0	6	0	36	6	52	0
116		54·0	6·8	100·6	134·1	75	0	34·5	5	0	52	9	232	0
117		41·0	7·8	97·8	99·8	60	0	22·7	7	0	36	6	110	0
125		52·0	7·1	98·0	99·7	70	0	27·6	7	0	46	9	108	0
130		56·0	8·0	98·5	99·1	65	0	24·7	6	0	41	0	133	0

NATIONAL INSTITUTE OF AGRICULTURAL BOTANY.

No.	Variety.	(1) Sub-Com- mittee's Estimate of market value in Jan., 1924.	(2) M L as % of Dry Matter.	(3) (4) Brewers' Extract.		(5) Sub-Com- mittee's Estimate of market value of Malt in Jan., 1924.	(6) Bushels per Acre.	(7) Return from tail corn per acre. All tail at 30s.	(8) Actual Value of 448 lb. Raw Barley. Dressed.	(9) Actual Value per Acre (pence excluded).
				per 336 Dry Malt.	per 448 Raw Barley.					
Grown at Cambridge.										
131	Beaven's 1920	1	8.9	97.2	100.1	54.0	131 badly hand- capped by damage during threshing.			serious
132	Webb's B.	2	8.5	98.4	101.4	53.0				
133	Golden pheasant ...	4	8.3	96.4	101.2	60.0				
134	Cambridge 59/120	3	8.7	98.1	101.0	61.0				
135	Control Garton 1917	5	9.4	97.1	100.2	48.0				
136	Beaven's 1920	1	8.5	97.0	98.4	61.0				
137	Webb's B.	4	9.0	98.5	100.5	60.0				
138	Golden Pheasant	3	9.0	95.5	98.0	59.0				
139	Cambridge 59/120	2	8.5	96.7	100.6	60.0				
140	Control Archer	5	8.9	96.0	97.9	53.0				
Grown at Kirton.										
141	Beaven's 1920	3	7.6	99.2	103.9	55.0	All coarse common malts.			
142	Webb's B.	1	8.8	99.2	103.4	53.0				
143	Golden pheasant	2	9.4	99.5	102.2	53.0				
144	Cambridge 59/120	4	9.0	97.0	100.7	54.0				
145	Control Garton 1917	5	8.6	95.9	100.2	51.0				
146	Beaven's 1920	4	8.6	97.1	101.0	51.0	All coarse common malts.			
147	Webb's B.	1	8.7	98.7	100.7	53.0				
148	Golden pheasant	3	9.6	99.0	101.4	53.0				
149	Cambridge 59/120	2	9.0	98.1	102.2	56.0				
150	Control Archer	5	9.4	95.7	98.8	49.0				
Grown at Market Weighton, Yorks.										
151	Beaven's 1920	1	4.7	99.6	103.6	61.0				
152	Webb's B.	4	5.6	99.2	98.7	53.0				
153	Golden Pheasant	3	6.1	99.5	102.0	57.0				
154	Cambridge 59/120	2	6.4	98.8	101.4	57.0				
155	Control Garton 1917	2	6.8	97.1	99.8	54.0				
156	Beaven's 1920	1	5.4	99.0	102.5	61.0				
157	Webb's B.	4	6.3	97.8	100.5	54.0				
158	Golden pheasant	3	6.8	99.5	101.7	59.0				
159	Cambridge 59/120	2	6.4	98.9	101.1	55.0				
160	Control Archer	4	6.8	95.6	96.7	52.0				
Grown at Norwich.										
166	Beaven's 1920	3	7.8	96.2	101.2	60.0	The Norwich malts were outstand- ing in comparison with those from barleys grown at other centres.			
167	Webb's B.	1	8.7	98.3	100.7	63.0				
168	Golden pheasant	4	8.9	98.0	101.9	59.0				
169	Cambridge 59/120	2	8.0	99.3	103.6	72.0				
170	Control Archer	5	8.8	96.9	100.2	56.0				

SUMMARY.

The results obtained from the barleys of the 1923 crop tend to confirm those obtained from the 1922 crop.

Other things being equal, soil and season are the predominant factors determining the "quality" of barley, and suitable plant food is necessary to obtain satisfactory yield, which can be got without prejudice to "quality."

Perhaps a word is necessary about market value. In assessing this (column 1), the Valuation Sub-Committee have to bear in mind, *not* necessarily what they would personally estimate the worth of the barley, but the amount of money they would have to pay for that barley in the market.

The word "quality" as applied to both

barley and malt is subject to much abuse. Appearance is often extremely deceptive and a study of the following figures for the Louth and Walcott stations will show how erroneous even expert empirical valuation may be.

	Market valuation per 448 lbs. raw barley dressed.	N. content. Malting loss. Calculated on dry matter.		Brewers' extract per 336 lbs. dry malt.	Actual value per 448 lbs. raw barley dressed.
Walcott*	41/6	1·80	8·34	96·7	36/-
Louth*	41/6	1·49	6·34	101·0	46/7

* Average of the five trials.

APPENDIX—ANALYTICAL RESULTS.

By H. LLOYD HIND, B.Sc., F.I.C.

THESE tables include only the results of such determinations as are usually undertaken for the technical valuation of Barley and Malt, carried out according to the Standard methods recommended by the Malt Analysis Committee of the Institute of Brewing. The extract is given as determined on the Malt. In the tables in the body of this report it is calculated to dry Malt.

The plot numbers refer to the manurial treatment as follows: (1) No manure. (2) Complete artificials. (3) Artificials without Potash. (4) Artificials without Phosphate. (5) Artificials without Nitrogen. The complete artificial manure is 1 cwt. sulphate of ammonia, 3 cwt. superphosphate and 1½ cwt. sulphate of potash per acre.

The barleys were sweated by being kept at about 110° F. for four days in a hot air room. They were then sent to the Maltings, the moistures varying between 11 and 14 per cent. as determined by drying in a Siau steam oven in a current of air at 97° to 98° Cent. The 1,000 corn weight and Nitrogen percentages were determined on the sweated barley. the results being calculated to dry barley.

The plot numbers refer to the manurial treatment as follows:—

- (1) No manure.
- (2) Complete artificials.
- (3) Artificials without Potash.
- (4) Artificials without Phosphate.
- (5) Artificials without Nitrogen.

The complete artificial manure is 1 cwt. sulphate of ammonia, 3 cwt. superphosphate and 1½ cwt. sulphate of potash per acre.

No.	Grower.	Plot.	Barley.			Malt.				
			Moisture, per cent.	1,000 corn weight dry, Grams.	Nitrogen per cent. on dry.	Moisture per cent.	Extract lb. per quarter.	Colour.	Diastatic Power. Lintner.	Cold water extract per cent.
2	Sir H. Hope, M.P., Barney- hill, E. Lothian.	1	16.15	39.2	1.587	1.54	98.1	4.2	29.0	18.5
3		2	15.98	37.8	1.684	1.70	97.1	4.7	34.0	19.0
4		3	15.92	37.0	1.820	1.88	95.4	4.5	34.0	19.0
5		4	16.50	38.3	1.740	1.78	96.2	5.0	34.0	18.8
6		5	16.36	36.5	1.726	1.56	96.7	4.5	32.5	18.8
14	A. E. Davy, Louth, Lincs.	1	19.10	42.5	1.405	1.80	99.6	3.5	35.0	18.3
15		2	18.54	41.2	1.356	1.70	100.1	3.7	35.0	17.8
16		3	18.68	41.7	1.575	1.88	99.0	3.5	40.0	18.1
17		4	19.10	42.4	1.568	1.80	98.6	3.5	37.5	18.3
18		5	19.32	42.0	1.533	1.64	99.1	3.7	38.0	18.0
19	G. H. Nevile, Wellingore, Lincs.	1	15.30	40.4	1.489	1.62	100.1	4.7	33.5	20.9
20		2	15.34	39.3	1.464	1.70	100.1	5.7	32.0	21.1
21		3	15.26	39.2	1.435	1.80	99.3	5.7	29.5	22.1
22		4	15.06	39.4	1.443	1.66	99.8	5.0	33.5	21.4
23		5	14.94	38.9	1.379	1.78	99.8	5.2	32.0	22.2
24	E. C. Tanner, Eyton-on- Severn, Salop.	1	16.64	36.6	1.818	1.76	96.4	5.0	39.0	19.6
25		2	16.54	39.3	1.634	1.76	99.0	5.2	34.5	19.4
26		3	16.78	36.4	1.645	1.70	98.3	4.7	34.0	17.3
27		4	16.34	41.0	1.794	1.98	98.1	4.7	38.5	18.2
28		5	16.48	39.8	1.590	1.70	100.1	4.3	33.5	17.4
29	R. A. Clarke, Chiselboro', Somerset.	1	17.76	40.3	1.494	1.64	99.3	3.7	33.5	19.0
30		2	17.41	41.0	1.396	1.70	99.5	4.0	33.0	19.7
31		3	17.78	40.4	1.536	1.60	99.2	3.7	33.0	19.3
31A		4	17.50	42.5	1.548	1.48	98.4	4.0	33.0	19.7
31B		5	17.46	43.3	1.518	1.58	98.4	4.5	—	—
32	Rt Hon. E. G. Pretyma, M.P., Nacton, Suffolk.	1	16.86	31.5	1.983	1.84	92.3	5.7	39.0	22.3
33		2	15.94	32.6	1.934	1.60	94.4	5.7	40.0	22.7
34		3	15.96	34.4	1.891	1.60	93.7	6.5	38.0	23.0
35		4	16.22	29.8	1.989	1.58	91.9	6.5	40.0	22.4
36		5	16.44	34.2	1.858	1.34	92.2	7.0	41.5	22.8
38	C. Bembridge, Walcott, Lincs.	1	17.02	41.9	1.869	1.80	94.4	6.2	40.0	21.6
39		2	16.64	43.6	1.815	1.88	95.6	6.2	39.5	20.7
40		3	16.98	43.3	1.806	1.84	93.7	6.5	34.0	22.6
41		4	17.64	43.5	1.794	1.90	95.4	6.2	36.0	20.3
42		5	18.06	44.0	1.726	1.90	95.4	6.2	34.0	20.7
43	B. Hill, Dereham, Norfolk.	1	18.10	34.2	1.945	1.92	93.8	6.2	43.0	21.9
44		2	18.46	34.7	1.994	1.74	93.2	6.2	40.5	22.7
45		3	18.54	35.9	2.059	1.88	93.0	7.0	46.0	22.4
46		4	18.74	35.8	2.013	1.78	93.7	6.5	46.0	22.6
47		5	18.16	34.5	2.015	1.56	95.0	6.2	44.5	22.1
48	J. H. Spilman, Beverley, E. Yorks.	1	19.05	38.5	1.293	1.84	98.1	4.2	24.0	19.7
49		2	19.36	41.6	1.337	1.88	97.4	4.0	27.2	19.4
50		3	18.90	40.4	1.379	1.78	97.1	4.0	28.0	19.5
51		4	18.82	40.4	1.385	2.12	96.3	4.0	29.5	19.3
52		5	19.68	38.6	1.302	1.92	97.1	3.8	27.2	18.9
53	Harper Adams College, Newport, Salop.	1	18.48	44.3	1.615	1.64	96.6	4.2	39.0	19.2
54		2	18.98	43.1	1.786	1.54	95.9	4.5	39.0	18.9
55		3	18.74	43.0	1.767	1.54	95.4	4.5	40.5	18.8
56		4	18.20	42.8	1.744	1.52	96.2	4.0	38.0	19.4
57		5	17.64	43.7	1.800	1.54	95.9	4.5	42.0	19.7

No.	Manurial treatment.	Plot.	Barley.			Malt.				
			Moisture per cent.	1,000 corn weight dry. Grams.	Nitrogen per cent. on dry.	Moisture per cent.	Extract lb. per quarter.	Colour.	Diastatic Power. Lintner.	Cold water extract per cent.
68	Woburn Experimental Station, Beds.	1	19.08	41.7	1.916	1.90	93.1	10.5	34.0	21.5
69		2	17.90	41.0	1.774	1.56	92.2	6.5	30.0	19.4
70		3	17.70	40.2	1.694	1.46	89.8	6.2	28.0	17.9
71		4	17.72	39.3	1.609	1.54	94.9	5.0	27.0	19.1
72		5	18.72	38.9	1.536	1.46	93.8	4.2	25.0	18.7
75	E. S. Beaven, Warminster, Wilts.	1	13.64*	43.6	1.527	1.34	100.2	5.2	38.0	21.9
76		2	13.64	41.5	1.464	1.40	101.0	5.0	38.0	22.6
77		(No N)	13.12	44.0	1.387	1.52	101.1	5.0	35.5	22.8
78		3	13.32	42.5	1.464	1.50	100.3	5.2	38.0	22.4
79		(N only)	13.68	44.0	1.507	1.62	100.1	5.0	38.0	21.6
80		1	13.40	45.1	1.564	1.62	99.3	5.5	40.0	22.5
81	Rothamsted Experimental Station, Harpenden, Herts.	1	16.38	—	1.707	2.16	97.1	6.5	37.0	22.7
82		2	17.04	43.2	1.544	2.04	99.0	6.3	32.5	22.7
83		3	17.80	41.7	1.549	1.82	99.4	6.5	31.7	21.9
84		4	17.98	42.4	1.578	1.96	99.0	5.2	33.3	20.8
85		5	17.00	41.3	1.648	2.06	96.3	7.0	34.2	22.9
86		(KCl)	16.28	41.0	1.629	2.14	99.8	5.0	30.7	21.2
87		(AmCl)	16.66	41.8	1.485	2.24	99.0	4.7	31.7	22.0

* Sweated.

OTHER ROTHAMSTED BARLEYS.

No.	Manurial treatment refer to plan on p. 106.	Plot.	Barley.			Malt.				
			Moisture per cent.	1,000 corn weight dry. Grams.	Nitrogen per cent. on dry.	Moisture per cent.	Extract lb. per quarter.	Colour.	Diastatic Power. Lautner.	Cold water extract per cent.
93	Permanent Barley Plots.	O1	19.10	40.2	1.734	1.08	93.3	7.0	41.5	21.7
94		O2	17.20	40.7	1.543	1.22	97.3	3.8	40.5	20.2
95		O3	18.58	39.5	1.708	1.26	96.9	7.3	40.5	22.0
96		O4	18.02	41.0	1.587	1.10	99.1	5.0	41.5	21.0
97		A1	16.84	41.7	2.072	1.20	94.7	4.0	45.0	20.7
98		A2	16.14	40.7	1.770	—	—	—	—	—
99		A3	16.46	43.3	1.913	1.10	94.4	3.7	46.0	20.9
100		A4	15.70	41.5	1.874	1.20	99.6	3.7	43.0	20.7
104		AA4	16.20	41.8	1.688	1.34	98.6	4.5	38.5	20.6
105		AAS1	16.42	44.2	1.934	1.22	94.9	5.2	41.5	21.9
106		AAS2	16.52	42.7	1.705	1.16	99.0	5.0	40.0	22.3
107		AAS3	17.02	45.0	1.810	1.10	96.4	5.5	40.0	21.5
108		AAS4	16.54	42.8	1.577	1.16	98.6	4.8	37.0	21.8
109		7-1	17.00	42.6	1.663	1.62	98.1	4.0	34.0	21.2
110		7-2	16.14	44.9	1.899	1.76	96.8	4.0	38.0	19.5
111		6-1 & 2	16.94	41.1	1.711	1.74	96.8	4.5	36.0	21.6
116	C4	16.80	43.6	1.697	1.14	99.5	3.7	40.0	20.5	
117		N2	16.94	43.5	1.831	1.40	96.4	4.8	38.0	21.1
125	Top dressing set.	2 & 9	18.12	44.2	1.807	1.40	96.6	4.7	41.0	22.1
130		7 & 14	17.60	43.1	1.793	1.40	97.1	4.7	40.0	22.1

BARLEYS FROM THE NATIONAL INSTITUTE OF AGRICULTURAL BOTANY.

No.	Grown at	Variety.	Barley.			Malt.				
			Moisture per cent.	1,000 corn weight dry. Grams.	Nitrogen per cent. on dry.	Moisture per cent.	Extract lb. per. quarter.	Colour.	Diastatic Power. Lintner.	Cold water extract per cent.
131	Cambridge.	Beaven's 1920.	15.07	41.8	1.71	1.98	95.2	4.7	36.0	19.5
132		Webb's B.	15.60	42.0	1.74	1.90	96.5	4.0	37.0	18.6
133		Golden Pheasant.	14.07	37.7	1.94	1.84	94.6	4.0	37.0	18.6
134		Cambridge 59/120.	15.47	36.8	1.89	1.84	96.3	4.5	34.0	19.4
135		Garton's 1917, used as Control.	14.58	39.5	1.91	1.76	95.3	6.3	35.0	18.7
136		Beaven's 1920.	16.70	40.1	1.84	1.62	95.4	4.5	35.0	18.8
137		Webb's B.	16.00	37.8	1.84	1.16	97.0	4.0	36.0	18.2
138		Golden Pheasant.	15.40	35.5	1.99	1.66	93.8	4.2	37.0	18.3
139		Cambridge 59/120.	14.67	37.5	1.82	1.66	95.0	4.2	35.5	18.6
140		Archer, used as Control	16.31	36.0	1.95	1.82	94.2	5.5	37.0	20.0
141	Kirtou.	Beaven's 1920.	14.70	43.1	1.65	1.76	97.4	4.5	40.0	19.6
142		Webb's B.	14.40	40.8	1.73	1.64	97.6	4.2	38.0	18.7
143		Golden Pheasant.	15.03	41.1	1.72	1.70	97.8	6.0	37.0	19.7
144		Golden Pheasant	14.47	38.1	1.87	1.80	95.2	4.7	38.0	19.2
145		Garton's 1917, used as Control.	14.42	39.1	1.77	1.78	94.1	4.5	38.0	17.7
146		Beaven's 1920.	14.60	38.3	1.79	1.70	95.4	5.0	40.0	20.2
147		Webb's B.	15.37	41.7	1.79	1.71	97.0	4.5	37.0	18.7
148		Golden Pheasant.	15.13	38.3	1.81	2.00	97.0	6.5	37.0	19.1
149		Cambridge 59/120.	11.23	36.8	1.76	1.72	96.4	4.5	38.0	19.1
150		Archer, used as Control	14.68	39.0	1.90	2.00	93.7	4.5	40.0	21.2
151	Market Weighton, Yorks.	Beaven's 1920.	18.15	39.0	1.34	1.62	98.0	3.5	32.0	18.2
152		Webb's B.	21.80	39.8	1.49	1.78	97.4	4.0	33.0	18.0
153		Golden Pheasant.	18.35	34.4	1.54	1.58	98.3	4.2	33.0	20.8
154		Cambridge 59/120.	17.90	36.5	1.52	1.54	97.3	4.0	32.0	19.9
155		Garton's 1917, used as Control.	18.50	38.0	1.44	1.38	95.7	4.5	34.0	18.4
156		Beaven's 1920.	17.80	38.4	1.34	1.66	97.4	4.0	36.0	18.7
157		Webb's B.	18.00	38.4	1.46	1.58	96.2	4.2	36.0	18.5
158		Golden Pheasant.	17.83	36.1	1.53	1.74	97.8	4.2	34.0	19.4
159		Cambridge 59/120	18.10	36.6	1.48	1.84	97.1	4.0	33.0	19.7
160		Archer, used as Control	18.64	36.3	1.48	1.58	94.0	4.2	34.0	17.9
166	Norwich.	Beaven's 1920.	14.53	41.5	1.83	1.74	94.5	4.0	37.0	19.6
167		Webb's B.	15.80	35.5	1.75	1.64	96.7	3.7	33.0	19.5
168		Golden Pheasant.	14.70	31.8	1.89	1.76	96.2	4.0	34.0	20.2
169		Cambridge 59/120.	14.97	33.8	1.68	1.72	97.6	3.7	32.5	20.5
170		Archer, used as Control	15.09	35.0	1.86	1.90	95.0	3.7	40.0	20.0

THE INSTITUTE OF BREWING RESEARCH SCHEME.

THIRD REPORT ON THE EXPERIMENTS ON THE INFLUENCE OF SOIL, SEASON AND MANURING ON THE QUALITY AND GROWTH OF BARLEY, 1924.

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THE field experiments have now gone on for three years, and are at present in their fourth; it is probable that by the end of the current season sufficient data will have accumulated to allow of some definite conclusions on the first of the three parts of the Sub-Committee's research programme, the influence of environmental conditions, soil, season and manuring, on the yield and quality of barley. It is proposed, therefore, at the conclusion of this season's work to reconsider the whole experimental plan with the view of proceeding to the further stage of making more extended malting trials with selected barleys, and finally of studying the third part of the programme: the relationship of the chemical composition of barley to malting and brewing value.

It is undesirable to prejudice this fuller treatment of the data by discussing the present season's results at length: little more than a record of the work will be given, with indications where the results agree with, and where they differ from, those of the preceding seasons. The agreement is close and affords gratifying evidence of the trustworthiness of the experimental results; the differences have thrown interesting light on certain apparent discrepancies and anomalies of the preceding two years.

The purpose of the experiments is to ascertain the influence of environmental conditions, such as soil, season and manuring, on the yield and quality of malting barley.

The experimental scheme comprises five plots, which are as follows:—

1. No manure.
2. Complete artificials: 1 cwt. sulphate of ammonia, 3 cwt. superphosphate, $1\frac{1}{2}$ cwt. sulphate of potash per acre.
3. Artificials without potash: 1 cwt. sulphate of ammonia, 3 cwt. superphosphate per acre.
4. Artificials without phosphate: 1 cwt. sulphate of ammonia, $1\frac{1}{2}$ cwt. sulphate of potash per acre.

5. Artificials without nitrogen: 3 cwt. superphosphate, $1\frac{1}{2}$ cwt. sulphate of potash per acre.

The variety tested is Plumage Archer. The same lot of seed is used throughout all the experiments, being specially selected by Mr. W. Hasler, of Dunnow. In respect of both seed and manuring, therefore, the experiments at the different centres are strictly comparable. At each centre, however, the barley is grown in its accustomed place in the rotation, and receives the cultivation judged best by the grower; this involves differences between the various centres, which on purely technical grounds can be abundantly justified.

The centres were practically the same as in the previous year, excepting that Mr. Hill, of East Dereham, found himself unable to continue, and Sir Harry Hope had no suitable land in his barley break. Two new centres were added in districts where further information was wanted: Wye, Kent, and Porlock, Somerset. The list for this season was:—

Eastern Side.

1. Rothamsted Experimental Station, Harpenden, Herts.
2. Beds. Woburn Experimental Farm. Dr. J. A. Voelcker.
3. Kent, Wye. South-Eastern Agricultural College. R. M. Wilson, Esq., Principal.
4. Essex, Dunnow. W. Hasler, Esq., Barnston Lodge Farm (G. Bellfield, Esq.).
5. Suffolk. Howes Farm, Martlesham. Rt. Hon. E. G. Pretyman, Esq., Orwell Park.
6. Norfolk Experimental Station, Newton St. Faith.
7. Lincs. Wellingore. G. H. Nevile, Esq.
8. Lincs. Walcott. C. Bembridge, Esq.
9. Lincs. Cawkwell. Scamblesby. Louth. A. E. Davy, Esq.
10. E. Yorks. Beverley. J. H. Spilman, Esq., Gardham Farm.

Western Side.

11. Shropshire. Eyton-on-Severn. E. Craig Tanner, Esq.
12. Shropshire. Newport. Harper Adams College. Dr. C. Crowther.
13. Stoke-under-Ham. R. A. Clarke and Sons, Chiselborough.
14. Somerset. Porlock. T. H. Rawle, Esq., Court Place.

The season.—The season of 1924 was remarkable for its prolonged wetness, its lack of sunshine and its long-drawn-out harvest—one of the most protracted of recent years. It was the wettest of all the 72 years of which records exist at Rothamsted, being considerably worse than 1879, the worst year in the 19th century; indeed, three times already in the 20th century the 19th century has been beaten: in 1903, 1912 and 1924. A wet, cold winter was followed by a hard, dry February and a dry, sunny March, which allowed the land to be well prepared for barley: the drilling was done under peculiarly favourable conditions; indeed, many barley land farmers had never seen spring corn go in so well. The spring was late, but barley started well; it was checked in May, however, by persistent rain and lack of sun. The latter half of June and the first part of July were the only reasonably dry periods of the summer, and the nine days from July 8th to the 16th were all that could be called sunny and warm. The corn came on well during this period. August, though not wetter than the average, was showery and sunless: ripening was slow and uneven, and cutting was later than usual.

The yields at the various centres were less affected than might have been feared: in the main they were much like those of 1923. At Wellingore and Orwell Park, however, they were higher, while at Woburn they were less. The quality was on the whole better than last year.

The results.—There had been no cross cropping, and all the results are collected in Table I. Owing to bad harvest conditions it was impossible to get weighings or samples from Beverley. The figures from Orwell Park are approximations only: they are recorded in the tables, but omitted from the discussion: here also samples were taken for analysis and malting. Out of the remaining 70 plots, only two appear to present irregularities, and even these appear capable of explanation. Plot 5, which received potash and phosphates, but no nitrogen, gave somewhat lower yields both at Rothamsted and

at Cawkwell than did the unmanured plots; this is contrary to the general behaviour. There is no doubt about the actual result. At Rothamsted the plots were triplicated, so that the error of the experiment is known: the differences were well outside the error. At Cawkwell the plots were large and were not replicated: a difference in any particular season might not be significant, but this result has been obtained in each of the three years, although the site of the plots has been changed each year.

The influence of nitrogenous manure on the yield of barley has been of the same order as in preceding years. The addition of 1 cwt. of sulphate of ammonia per acre increased the yield of total grain by 5 bushels per acre and of dressed grain by 4·3 bushels. For all the centres for the years of the experiment the average increase has been 5·4 bushels of dressed grain. This smallness of variation in effect has been pointed out in earlier Reports. There were increases in total grain at every centre, varying from 1·8 bushels at Woburn to 9·5 bushels at Rothamsted: there were also increases in dressed grain at every centre but Harper Adams. The gains at the different centres have been:—

Centre.	Bushels per acre.	
	Total.	Dressed.
Rothamsted	9·5	7·3
Woburn	1·8	1·7
Wye	2·0	0·4
Dunmow	5·0	4·6
Porlock	3·7	3·8
Newton St. Faith	5·7	5·7
Wellingore	5·6	5·6
Walcott	6·3	3·7
Cawkwell	8·6	8·6
Eyton	4·2	3·9
Harper Adams	4·6	—
Stoke	3·4	6·0
Mean	5·0	4·3

The effect of phosphate has been very small: on an average 3 cwt. superphosphate has added less than half a bushel to the crop. Only at Newton St. Faith, Walcott and Stoke was there any notable gain; at Newton St. Faith it amounted to 8·9 bushels: at Stoke it was 6·0 bushels of dressed grain and 3·7 of total: at Walcott 3·0 bushels of dressed grain and 3·7

of total. Elsewhere the gains were small and set off by losses of the same order. At Woburn there was an apparent gain through the omission of phosphate, which will be further studied.

The omission of potash has led to very interesting results. It will be recalled that in 1922 and 1923, potash had had but little effect on the yield, but at some centres it apparently depressed the yield. This year the depression has occurred at seven centres, including Rothamsted, on the triplicate plots, where there is no doubt about its significance. On an average, the result of adding $1\frac{1}{2}$ cwt. sulphate of potash has been to reduce the yield by just under one bushel of total grain and $1\frac{1}{2}$ bushels of dressed grain. There were depressions of 4 bushels at Rothamsted, of 3 at Woburn, Eyton, Porlock and Wye, and of 7 at Dunmow and Wellingore: this depression had been observed before at Wellingore. To whatever the adverse effect is due, it is something more clearly emphasised in some seasons than in others, and it was particularly marked in 1924. There have for some time been suspicions that potash might in certain circumstances be harmful to barley, but never before have so many observations on the subject been recorded. The data are being examined and the problem further studied in the laboratories at Rothamsted.

The effects on the yield resulting from the omission of phosphate and of potash are as follows:—

Centre.	Phosphate.		Potash.	
	Bushels per acre.			
	Increase + or decrease —.			
	Total.	Dressed.	Total.	Dressed.
Rothamsted	+ 0.7	+ 1.2	+ 3.9	+ 4.6
Woburn	+ 9.3	+ 9.2	+ 3.0	+ 3.0
Wye	+ 1.5	+ 1.8	+ 3.0	+ 3.7
Dunmow	+ 2.1	+ 2.1	+ 6.8	+ 6.9
Porlock	+ 1.8	+ 1.8	+ 2.7	+ 2.7
Newton St. Faith	- 8.9	- 8.9	- 5.3	- 5.3
Wellingore	- 0.9	- 0.9	+ 7.4	+ 7.4
Walcott	- 3.7	- 3.0	- 1.8	- 1.5
Cawkwell	- 2.2	- 2.0	- 4.9	- 4.1
Eyton	—	—	+ 3.2	+ 3.6
Harper Adams	- 1.3	- 0.6	- 1.2	- 1.9
Stoke	- 3.7	- 6.0	- 5.4	- 6.0
Mean	- 0.4	- 0.4	+ 0.9	+ 1.1

These results, taken in conjunction with those of previous years, raise a number of points of interest to the barley grower, and they emphasise the need for revising the recommendations often made to farmers by agricultural experts as to the manurial treatment of barley.

Agricultural experts commonly base their advice on the Hoos Field results at Rothamsted. These have been analysed in great detail, first by Lawes and Gilbert and afterwards by Hall, and the deduction was drawn that the manuring of barley should be mainly, if not entirely, phosphatic, nitrogen being given only in certain circumstances and potash only rarely. This advice has been followed by the fertiliser manufacturers, and the compound manures sold for barley consist mainly of superphosphate and like substances.

Two of the most popular recommendations were:—

Barley after a straw crop. $\frac{1}{2}$ to $1\frac{1}{2}$ cwt. sulphate of ammonia; 3 cwt. superphosphate; no potash except on light soils only; then $\frac{1}{2}$ cwt. sulphate of potash.

Barley after roots fed off. No nitrogen; 3 cwt. superphosphate; no potash.

The results obtained during the past three seasons do not bear out these recommendations: the average reduction in yield in bushels per acre consequent on the omission of each fertiliser during the three years 1922, 1923 and 1924 has been:—

Decrease due to omission of.	After a straw crop	After roots fed off.	After potatoes or beets (well manured).	Mean of all experiments.
1 cwt. sulphate of ammonia	5.8	3.9	6.7	5.4
3 cwt. superphosphate	0.9	(0.5)	1.2	0.5
$1\frac{1}{2}$ cwt. sulphate of potash	(1.1)	1.3	1.1	0.4

(Figures in brackets are increases and not decreases.)

It is interesting to note that on Hoos Field the application of 100 lb. sulphate of ammonia per acre gave an additional $5\frac{1}{2}$ bushels of grain during the first five years of the experiment (1852-1856), an increase agreeing well with the

value 5·4 bushels in these experiments. This uniformity in action of nitrogenous fertilisers is very striking, and is in marked contrast with the behaviour of phosphatic and potassic fertilisers, the results of which cannot usually be predicted.

It is not proposed to anticipate the fuller discussion of next year, but the following facts are impressive :—

1. The addition of a nitrogenous fertiliser has on all but a few soils (mainly those known to be rich) led to an increase in crop which for all the tests averages 5·4 bushels per cwt. of sulphate of ammonia. Increases have been obtained whether the barley was grown after a straw crop, after roots fed off, or after potato and beet crops.
2. The use of 3 cwt. superphosphate per acre has given only a slight and unprofitable response after a straw crop or after potatoes and beets, and none at all after roots fed off.
3. The use of sulphate of potash has given small increases in crop after potatoes, less after roots fed off and none after a straw crop.

It will be seen at once that these results do not support the accepted recommendations. Nitrogenous manure has increased the yield even after roots fed off, and would in most cases have paid well; while the phosphatic manure which forms the basis of the usual manurial receipt, and is indeed the only thing recommended for barley after roots, gave no return on the average. Out of the whole of the 30 tests recorded, the farmer who had followed the standard recommendation would have gained in 4 and incurred a loss in the remaining 26. These tests are made on actual commercial farms on large plots often of an acre or more in size, and the possibilities of improving the manurial receipt are shown by the fact that, at the various centres, one or other of the schemes of manuring gave increases in crop representing actual cash values varying up to £5 or even £6 per acre. There are probably three reasons why the older recommendations should have proved unsatisfactory :—

1. Modern high-quality varieties of barley, such as the Plumage Archer, used in these experiments have stiffer straw than the older ones, and therefore can carry

larger crops of grain without risk of being lodged. Thus they can safely receive more nitrogenous manuring.

2. The striking results of phosphates in the Hoos Field experiments have been too literally applied to ordinary farm conditions. The soil is heavy, and heavy soils usually respond well to phosphates; the effects are here further intensified by the circumstance that this soil is far more exhausted of phosphate than is usual. In practice, however, barley is usually grown on lighter soils, where the need for phosphates is not so pronounced.
3. Most farmers use liberal dressings of phosphates for their roots. The barley, therefore, can usually find in the soil most of what it needs; potash is also added in the rotation to the potato, mangold, sugar beet or to certain leguminous crops.

The valuation of crops.—This was done on February 25th, 1925, in the same manner as in previous years, by a sub-committee consisting of Messrs. Cherry-Downes, Lancaster, Reid and Wightman. The results are set out in Table III. and range from 50s. to 90s. per quarter, these values being considerably above those assigned for 1923, 39s. 6d. to 57s., or, for 1922, 30s. to 65s. It must again be emphasised, however, that the figures represent market values on a similar system of valuation, and they do not imply that the barleys of 1924 were correspondingly higher in quality than those of the previous year.

The most interesting comparison is between the samples that received nitrogenous manuring and those that did not. The addition of the nitrogen raises the yield, as is well known, but agriculturists usually fear that the valuation will be depressed; our experiments afford no justification for this fear. In none of the three seasons has the effect of the nitrogenous manuring on the valuation been more than slight: usually, indeed, it has somewhat increased the valuation, and in 1924 there was a depression only at Wellingore.

The influence of potash and of phosphates has again been slight. Omission of phosphates caused a slight reduction in valuation at Cawkwell and a larger one at Woburn; elsewhere there is no apparent effect. Omission of potash caused a reduction in valuation only on

the very light sand of Orwell Park. Again these results do not agree with the current teachings of agricultural science. The usual recommendation in aiming at high quality is to give phosphates and to withhold nitrogen. These experiments, on the other hand, show that the use of nitrogenous manure, even after roots folded off, has not adversely affected the valuation of the barley (or in previous years the value of the malt), but that the omission of potash from the manure lowered some of the desirable qualities of the malt in 1922, though apparently not in 1923 or 1924. At each centre the heaviest crops obtainable by manuring have been valued as high or nearly as high per quarter as any other samples of the same set, and it is clear that manurial schemes can be devised which will enhance the present yield without detriment to valuation. So far as the investigation has gone, it suggests that farmers using a good modern variety of barley can aim at the biggest crop that will stand, and they can use the appropriate fertiliser to secure this without fear of loss of valuation.

The value of the crops to the farmer.—This is set out in Table V, which has been calculated in the same way as in previous years. The cost of growing the crop at Rothamsted was £11 8s. 7d. per acre, as against £10 14s. 0d. last year, and on the lighter Woburn soil it was £6 17s. 0d.* per acre, while at the centre reported in previous years it was £7 3s. 5d., as against £7 2s. 0d. last year, the cost of manure being in all cases omitted.

Nitrogen content of grain and valuation.—The average nitrogen contents and the averages of the valuations of the samples from the different plots are given below. It will be observed that the nitrogen content is considerably less this season than it was in 1922 or 1923. The detailed results are shown in Tables II and III.

Porlock and Woburn are the highest in value, and also, with the exception of Cawkwell, the lowest in nitrogen content. The Cawkwell barley is, as usual, assigned a lower valuation than its nitrogen content would suggest; both in 1923 and 1924 the malting results accorded better with the nitrogen figure than with the valuation.

At the other end of the nitrogen scale the barleys of highest nitrogen content are, with

* Nothing is included here for general expenses which at the other centre amounted to £1 2s. 9d. per acre.

Centre	Average Nitrogen per cent. on dry barley.	Average Valuation, shillings per quarter.	Previous Results Average Nitrogen content.	
	1924.	1924.	1922.	1923.
Cawkwell	1.223	64.2	1.52	1.49
Woburn	1.227	82.4	1.95	1.71
Porlock	1.303	88.8	—	—
Newton St. Faith	1.319	70.4	—	—
Eyton	1.361	66.8	1.92	1.70
Wellington	1.421	71.0	1.79	1.44
Dunmow	1.463	69.0	1.77	—
Stoke	1.464	72.8	—	1.50
Orwell Park	1.517	67.6	1.51	1.93
Harper Adams	1.557	50.0	—	—
Rothamsted	1.563	63.2	1.62	1.61
Walcott	1.583	63.0	1.79	1.80
Wye	1.708	74.0	—	—

the exception of Wye, the lowest in price. The Harper Adams sample was in very poor condition and receives a low valuation. There is only a slight connection this year between nitrogen content and valuation. This is explained partly by the condition of the barleys, which was an important factor in market valuation, and partly by the generally low nitrogen content of the barleys, as there is little evidence that a nitrogen content up to 1.6 per cent is prejudicial to the malting value of English barley.

These results will be more appropriately discussed next year, when fuller data are available.

Influence of manuring on nitrogen content of barley.—As usual, the complete manure has lowered the percentage of nitrogen in the grain compared with no manure. Harper Adams and Walcott afford the only exceptions; at Harper Adams the percentage is raised, and at Walcott it is unaltered. Usually the lowered nitrogen percentage is associated with a higher valuation. Last year and in 1922 the omission of nitrogenous fertiliser usually lowered the percentage of nitrogen in the grain; this year it has done so only at two centres, Wye and Newport. Elsewhere it has been without effect or has actually increased the nitrogen. This increase occurred at Rothamsted, Orwell Park, Dunmow, Stoke-under-Ham, Woburn and

TABLE I.
MALTING BARLEY RESULTS, 1924.
*Dressed grain, bushels per acre.**

No.	Treatment.	Stiff Soils.		Medium Soils.			Light Soils.			Very Light Soils.		Chalk.		Fen.
		Roth-amsted.	Dun-mow.	Eyton on-Severn	Well-in-gore.	Por-lock.	Har-per Adams	Stoke-under-Ham.	New-ton St. Faith.	Wo-burn.	Or-well Park.	Cawk-well.	Wye.	Wal-cott.
1	Nil ...	24.65	27.9	29.27	43.3	21.76	36.42	27.0	32.7	21.3	12.0	40.2	51.8	46.0
2	All (a)	27.68	38.3	49.07	50.8	31.83	34.40	33.0	47.5	27.9	25.0	42.2	53.3	52.6
	(b)	26.78												
	(c)	28.00												
3	Less K ...	32.3	45.2	52.62	58.25	34.59	32.48	27.0	42.2	30.9	26.0	38.1	57.0	51.1
4	Less P	28.9	40.4	49.32	49.9	33.67	33.82	27.0	38.6	37.1	27.0	40.2	55.1	49.6
5	Less N ...	20.37	33.7	45.13	45.2	28.00	34.60	27.0	41.8	26.2	28.0	33.6	52.9	48.9
Total grain : Unmanured = 100.														
1	Nil	100	100	100	100	100	100	100	100	100	100	100	100	100
2	All (a)	122	137	166	117	143	106	112	150	130	208	105	103	114
	(b)	120												
	(c)	124												
3	Less K	136	161	177	134	155	103	94	133	144	217	95	110	111
4	Less P ...	124	145	165	115	151	103	99	118	173	225	100	106	108
5	Less N ...	87	120	152	104	127	95	99	128	122	234	84	102	106
Dressed grain : Unmanured = 100.														
1	Nil .	100	100	100	—	100	100	100	—	100	—	100	100	100
2	All (a)	112	137	168	—	146	94	122	—	131	—	105	103	114
	(b)	109												
	(c)	114												
3	Less K	131	162	180	—	159	89	100	—	145	—	95	110	111
4	Less P	117	145	169	—	155	93	100	—	174	—	100	106	108
5	Less N	83	121	154	—	129	95	100	—	123	—	84	102	106

The figures for Wellingore and Newton St. Faith are for total grain, but the quantity of tail corn was negligible.

* 56 lb. bushels. (a) Complete artificials, sulphate of ammonia. (b) Complete artificials, muriate of potash. (c) Complete artificials, muriate of ammonia.

Porlock; at the last three centres the increased nitrogen content was associated with a lower valuation.

The omission of phosphatic fertilisers increased the nitrogen content at 7 out of 12 centres; it had also acted in this way in 1923, but not

in 1922; only at 2 centres (Wellingore and Woburn) out of the 7 was there a fall in valuation. The omission of potash had a more marked action than in previous years and increased the nitrogen content at eight centres, but did not at more than two lower the valuation.

Influence of chlorides on barley.—The farmer has the option of using chlorides (or muriates) of ammonium and of potassium instead of the sulphates, and there are certain important technical differences between the two kinds of fertilisers. The comparison has been made at Rothamsted, and it gave such interesting results that it is being extended to certain other centres. In every test at Rothamsted the valuation of the grain has been raised and its nitrogen content lowered by using ammonium chloride instead of ammonium sulphate. This is shown by the following table:—

Season.	Valuation of Barley per qr. of 448 lb.		N. in grain; per cent. of dry matter.	
	Ammonium Sulphate.	Ammonium Chloride.	Ammonium Sulphate.	Ammonium Chloride.
1922	<i>s. d.</i> 31 0	<i>s. d.</i> 36 0	1.647	1.602
1923	57 6	58 0	1.544	1.485
1924	63 6	64 0	1.517	1.495

The result is all the more interesting in that this is the only manurial method hitherto tested which has consistently improved the quality of the grain. Other treatments have acted sometimes one way and sometimes the other, the change being usually small and unpredictable.

When yield is combined with the valuation, and allowance is made for tail corn, there is found to be a considerable difference in money value per acre in favour of the chloride:—

Yield (measured bushels per acre) and money value of barley per acre.

Season	Ammonium Sulphate.		Ammonium Chloride.		Difference in favour of Chloride as against Sulph.
	Yield.	Money value per acre.	Yield.	Money value per acre.	
1922	36.0	<i>s.</i> 136	35.7	<i>s.</i> 156	<i>s.</i> 20
1923	32.5	239	35.6	265	26
1924	29.8	238	29.7	249	11

TABLE II.

VALUE PER ACRE OF DRESSED GRAIN TO NEAREST SHILLING.

	Plot.	Rothamsted.	Dunmow.	Eyton-on-Severn.	Wellington.	Porlock.	Harper Adams.	Stoke-under-Ham.	New-ton St. Faith.	Woburn.	Orwell Park.	Cawkwell.	Wye.	Walcott.
1	None ..	<i>s.</i> 185	<i>s.</i> 234	<i>s.</i> 241	<i>s.</i> 390	<i>s.</i> 237	<i>s.</i> 227	<i>s.</i> 250	<i>s.</i> 278	<i>s.</i> 213	<i>s.</i> 101	<i>s.</i> 326	<i>s.</i> 479	<i>s.</i> 362
2	All ..	221	326	406	450	357	214	305	427	314	219	343	494	414
3	„ less K	258	396	434	510	389	205	250	379	347	208	310	528	402
4	„ less P	231	354	407	436	378	212	250	347	371	236	316	510	391
5	„ less N	163	295	395	407	305	216	230	355	236	234	265	489	385

TABLE III.
VALUATION AND PERCENTAGES OF NITROGEN IN THE VARIOUS SAMPLES. NITROGEN PER CENT.
ON DRY BARLEY. PRICE PER QUARTER.

	Dunmow.		Cawkwell.		Wellingore.		Eyton-on-Severn.	
	Per cent. Nitrogen.	Price.	Per cent. Nitrogen.	Price.	Per cent. Nitrogen.	Price.	Per cent. Nitrogen.	Price.
1. No Manure	1.564	s. 67	1.266	s. 65	1.424	s. 72	1.388	s. 66
2. Complete Manure .. .	1.447	68	1.199	65	1.404	71	1.374	66
3. No Potash	1.438	70	1.253	65	1.403	70	1.361	66
4. No Phosphate	1.425	70	1.204	63	1.449	70	1.328	66
5. No Nitrogen	1.460	70	1.194	63	1.400	72	1.356	70
Average	1.463	69	1.223	64.2	1.421*	71*	1.361	66.8

	Stoke-under-Ham		Orwell Park.		Walcott.		Newton St. Faith.	
	Per cent. Nitrogen.	Price.	Per cent. Nitrogen.	Price.	Per cent. Nitrogen.	Price.	Per cent. Nitrogen.	Price.
1. No Manure	1.461	s. 74	1.591	s. 67	1.581	s. 63	1.334	s. 68
2. Complete Manure	1.403	74	1.407	70	1.586	63	1.286	72
3. No Potash	1.510	74	1.631	64	1.613	63	1.363	72
4. No Phosphate	1.495	74	1.433	70	1.560	63	1.324	72
5. No Nitrogen	1.451	68	1.521	67	1.575	63	1.289	68
Average	1.464	72.8	1.517	67.6	1.583	63	1.319	70.4

	Harper Adams.		Wye.		Porlock.		Woburn.		Rothamsted.	
	Per cent. Nitrogen.	Price.	Per cent. Nitrogen.	Price.	Per cent. Nitrogen.	Price.	Per cent. Nitrogen.	Price.	Per cent. Nitrogen.	Price
1. No Manure	1.508	s. 50	1.741	s. 74	1.295	s. 87	1.230	s. 80	1.620	s. 60
2. Complete Manure	1.624	50	1.708	74	1.266	90	1.161	90	1.517	64
3. No Potash	1.631	50	1.748	74	1.326	90	1.173	90	1.540	64
4. No Phosphate	1.506	50	1.750	74	1.268	90	1.259	80	1.525	64
5. No Nitrogen	1.514	50	1.592	74	1.359	87	1.310	72	1.611	64
Average...	1.557	50	1.708	74	1.303	88.8	1.227	82.4	1.563	63.2

* For Plots 1-5.

TABLE IV.
MOISTURE PER CENT. IN GRAIN.

	Dun- mow.	Cawk- well.	Eyton- on- Severn	Stoke- under- Ham.	Or- well Park.	Wal- cott.	New- ton St. Faith.	Har- per Adams	Wye.	Por- lock.	Wo- burn.	Roth- am- sted.	Well- in- gore
1. No Manure ..	19.44	20.32	17.75	20.22	19.32	18.50	18.16	17.12	19.50	17.85	19.26	16.10	17.88
2. Complete Manure	17.28	20.54	17.46	19.87	18.44	18.13	18.42	17.86	20.12	16.64	18.75	17.00	17.82
3. No Potash	18.24	19.94	17.54	19.94	19.26	18.30	18.70	16.82	20.72	17.60	18.56	17.28	18.00
4. No Phosphate	18.12	20.49	17.39	20.03	18.44	18.36	17.28	16.30	21.04	17.28	18.57	17.32	18.21
5. No Nitrogen	16.94	20.85	17.76	20.06	19.10	18.44	18.18	16.84	21.58	16.81	18.76	17.06	18.25 †16.76
Average	18.00	20.43	17.58	20.02	18.91	18.35	18.15	16.99	20.59	17.24	18.78	16.95	*18.03

* Average for Plots 1-5 only.

† Surface sown after beet residues.

TABLE V.
1,000 CORN WEIGHT IN GRAMS CALCULATED TO DRY BARLEY.

	Dun- mow.	Cawk- well.	Eyton- on- Severn	Stoke- under- Ham.	Or- well Park.	Wal- cott.	New- ton St. Faith.	Har- per Adams	Wye.	Por- lock.	Wo- burn.	Roth- am- sted.	Well- in- gore
1. No Manure ..	39.1	36.9	39.2	36.4	42.7	42.8	33.0	39.2	40.5	38.6	37.6	40.6	39.2
2. Complete Manure	40.0	37.2	39.6	37.4	39.0	44.4	34.2	39.1	39.2	39.4	37.3	42.4	39.3
3. No Potash	39.2	38.0	40.0	38.0	41.2	43.1	32.8	40.6	38.8	38.9	35.8	42.2	40.9
4. No Phosphate	40.4	37.1	40.0	38.1	38.2	42.4	33.7	39.8	39.1	37.2	39.6	41.5	38.8
5. No Nitrogen	41.3	37.7	39.2	37.0	42.1	43.3	34.5	38.6	39.4	39.8	38.6	42.2	40.3 †38.9
Average	40.0	37.4	39.6	37.4	40.6	43.2	33.6	39.5	39.4	38.8	37.8	41.8	*39.5

* Average for Plots 1-5 only.

† Surface sown after beet residues.

APPENDIX I.

Centres.	Particulars of soil, field and size of plot.	Previous cropping and manuring.	Date of sowing 1924. Rate of seeding.	Date of applying manure.	Date of cutting.	Date of carting.	Season.
EASTERN SIDE.							
<i>Herts</i> — Kothamsted Experimental Station.	Soil clay with flints. Heavy strong soil overlying chalk. Great Harpenden Field. $\frac{1}{2}$ acre in triplicate.	Winter wheat unmanured.	March 20th. 10 pecks per acre.	March 17th	Aug. 18th and 19th.	Sept. 11th	<i>See p. 2.</i>
<i>Kent</i> — South-Eastern Agricultural College, Wye.	Loam overlying chalk. "A" Field. $\frac{1}{2}$ acre in triplicate.	Mangolds: dung and complete artificial.	March 19th. 12 pecks per acre.	March 18th and 19th	Aug. 18th	Sept. 9th and 10th	Wet season generally. Particularly stormy at time of ripening. Heavy rain accompanied by very strong wind.
<i>Beds</i> — Woburn Experimental Farm. Dr. J. A. Voelcker.	Sandy loam, junction of Lower Greensand and Oxford Clay, deep, low lying, apt to be wet. Stack-yard Field. $\frac{1}{2}$ acre.	Black winter oats unmanured.	March 11th. 12 pecks per acre.	March 11th	Aug. 12th	Sept. 1st	March, cold; spells of frost; rainfall slight. April early cold and dry, then hot followed by showery weather. May wet but warm. Fine and dry for 10 days before and 7 days after cutting, then dull and wet till date of carting.
<i>Essex</i> — Dunmow. W. Hasler, Esq. Felstedbury Farm.	Medium to heavy clay loam. Lane Field. $1\frac{1}{2}$ acres.	Wheat: 5 cwt. Seychelles guano, 2 cwt. kainit, 1 cwt. sulphate of ammonia.	March 17th and 18th. 10 pecks per acre.	March 15th	Aug. 25th	Sept. 11th	Dry spell giving excellent seed bed: then cold weather and 14 in. of rain out of annual 20 in. by June 10th.
<i>Suffolk</i> — Orwell Park, Ipswich. E. G. Pretymann, Esq.	Light sand on sand. Lineside Field. 2 of 4 acres, 3 of half an acre.	Colewort and mustard folded.	April 7th. 8 pecks per acre.	April 7th	Sept. 15th	Sept. 15th	Fine for seeding with heavy rain late May and continuing wet: cutting delayed by weather.
<i>Norfolk</i> — Norfolk Agricultural Station. St. Faith's, Norwich.	Light loam overlying gravel. Loke Piece Field. $\frac{1}{2}$ acre in duplicate.	Swedes: 3 cwt. superphosphate.	April 5th. 12 pecks per acre.	April 3rd	Aug. 20th	Aug. 28th	April cold with severe night frosts. May wet (3-8 in. rain). Later season very rainy, but harvested fairly well.

<i>Lincolnshire</i> — Wellingore. G. H. Neville, Esq.	Oolitic limestone. Lincoln heath light loam: about 8 in. soil. High Dyke Field. 3 acres.	Potatoes (heavy crop) 3 cwt. super- phosphate, 1 cwt. sulphate of pot- ash. 1 cwt. sul- phate of ammo- nia. 1 cwt. nitrate of soda. 10 loads farmyard manure. Winter oats un- manured.	March 13th. 10 pecks per acre.	March 28th	Aug. 25th	Sept. 18th	February and March dry with night frosts when it rained till March 23rd; dry till April 13th; rainy spell till May 13th. Harvested under rainy conditions.
<i>Walcott.</i> C. Bembridge, Esq., Timber- land Farm. Cawkwell. A. E. Davy, Esq.	Black fen soil with clay and silt sub- soil. 2 acres.	Winter oats un- manured.	March 10th and 11th. 12 pecks per acre.	March 10th and 11th.	Aug. 20th	Sept. 12th to 13th.	Exceptionally rainy in late April and May. Stormy and unsettled during whole summer.
	Chalk wolds, red rather heavy loam overlying chalk 6-12 in. down. Middle Walk Field. 2 acres.	Turnips folded	March 25th. 10 pecks per acre.	March 27th	Aug. 25th	Sept. 15th	Plenty of rain, little sun. Good before cutting. Show- ery weather till carting.
<i>WESTERN SIDE.</i> <i>Shropshire</i> — Harper Adams College, New- port.	Sandy loam over- lying lower Trias. Lower Foxhills Field. ½ acre.	Swedes: 8 tons farmyard manure. 4 cwt. basic slag. 3 cwt. steamed bone flour. 1 cwt. sulphate of am- monia. 2½ cwt. kanit.	April 8th. 10 pecks per acre.	April 8th	Sept. 2nd	Sept. 29th	Very little rain till April 18th, after which abundant rain.
<i>Eyton-on-Severn.</i> E. Craig Tanner, Esq.	Trias red medium, loam gravelly. Al- lens Field. 1 acre.	Swedes: 6 cwt. bone meal.	March 14th. 9 pecks per acre.	March 28th	Aug. 10th	Sept. 15th	Wet season generally. Rain before harvest and showery throughout.
<i>Somerset</i> — Stoke-under- Ham. Chisel- borough. Messrs. R. A. Clarke & Sons. Porlock. R. H. Rawle, Esq.	Inferior Oolite light sandy soil. North hill Field. 1 acre.		Feb. 19th. 8 pecks per acre.	Feb. 20th	Aug. 17th	Aug. 25th	Unusually rainy in May.
	Stonebrash derived from Red Sand- stone. Eight acres Field. ¾ acre.	Winter oats fol- lowed by catch crop of turnips folded.	March 20th. 10 pecks per acre.	March 20th	Aug. 25th	Sept. 3rd	Cold and dry early in April followed by much rain. Cut in rain but stacked and carted in fine weather.

NOTE.—There are 4 pecks to 1 bushel.

APPENDIX II.

FARMERS' AND ROTHAMSTED STAFF'S REPORT
ON GROWING CROPS.*Rothamsted.—Summary of Season's Observations.*

The barley went in well and progressed favourably until the rains of May. Plots 1 and 5 (no manure and no nitrogen) looked lighter in colour, and Plot 3 (no potash) darker than the completely manured. Plots 1 and 5 lagged behind 2, the completely manured plot, throughout the season in all characteristics, height, leaf emergence, leaf width, total height, shoot height and ear height. Plot 1 was the less advanced of the two in total height till June 16th and in shoot height and ear height till August 2nd, after which the No Nitrogen Plot No. 5 was the less advanced of the two. Plot 3 (No Potash) lagged behind 2, the complete manure, till July 1st, when it overtook Plot 2 in total and "shoot" height and later on in ear height. The grain samples of Plots 1 and 5 were the highest in moisture content throughout the latter end of the growing season and in the sheaves.

W. Hasler. Dunmow. 1924.

May 27th.

No plot looks really well. No. 1 very yellow after the heavy rainfall.

June 10th.

Plot 1. Yellow, poor tillering, good height compared with barley generally, $5\frac{1}{2}$ leaves. Roots trying to put out adventitious branches high up coleoptile. Poor and not many fibrous roots. Ear formed.

Plot 2. More tillering (3 or 4). Stoutier shoot and broader leaf. 3 nodes easily discernible, considerable lengthening of inter-nodes; colour better; fibrous root system more developed.

Plot 3. Tillering as 2. Leaves shorter. Nodes less marked. Roots as 2. Thinner in shoot perhaps.

Plot 4. Stands perhaps a little less well than 2, but tillers and roots well developed. 3 nodes quite easily found.

Plot 5. Almost as poor as Plot 1. Leaf diminished. Nodes poorly developed. Internodes short. Yellow in colour. Roots less fibrous than 2, better than 1, showing surface spreading.

General.—Good, considering season. Previous manuring probably helped. The N dressing effective even in this abnormal season.

Orwell Park. 1924.

May 28th.

Plot 4 appeared the best, closely followed by Plot 3. Plot 5 the poorest.

June 11th.

Plot 2. Growth fair, but inclined to be spindly. Colour poor. Roots showing signs of water logging. Tillering good 3 to 4, but latest tillers dying, leaves fairly broad.

Plot 4. Slightly less leaf than 2. Shorter in internodes. Roots as 2, tillering good, colour equal to 2. Stands a little straighter than 2.

Plot 5. Much thinner, drill rows visible. Tillering normal, roots not water-logged. Leaf small, less dying-off of leaves. Only just beginning to shoot.

Plot 3. At present a good-looking crop compared with the rest. Tillers and roots as 2. Good broad leaves and internodes.

Plot 1. As 5, roots less fibrous, leaves less spreading, no nodes.

General.—Looking poorer than that sown a month ago.

St. Faith's. Norwich. 1924.

May 23rd.

Plots 2 and 1 show the most marked contrast. The difference is greater than in most years at this stage.

June 11th.

Plot 1. The poorest plot of all; poorer than 5. Drill rows plainly visible.

Plot 2. Good plot, but not very markedly better than other plots receiving Nitrogen.

Plot 3. Less leaf, less roots than 2 or 4. Colour good. Straw soft, drill rows visible. Commencing to shoot.

Plot 4. Good leaf, roots fairly fibrous, tillering good. Colour superior to 5, but shoot not noticeably superior, 2 nodes observable.

Plot 5. Colour fair. Root poor, 2 nodes, good tiller, long internodes.

General.—The effect of Nitrogen has not shown markedly.

August 19th.

Plot 1. Straw 17 to 23 inches. No sign of lodging. Slight unevenness in ear emergence.

Plot 2. Straw 27 to 30 inches; well developed and even in ear, no lodging.

Plot 3. Straw 25 to 30 inches. Tendency to lean. Grain not so regular in ripening.

Plot 4. Straw 23 to 27 inches, no tendency to lean. Good plump grain.

Plot 5. Straw 18 to 24 inches. Ears unevenly developed.

Wellingore.

May 28th.

Plots with nitrogenous manure showing up better than in previous years owing to good growing season.

June 12th.

Plot 1. Thin, poorer than 5, leaves narrow and less spreading. Root poor, height 15 inches, internodes 2 inches, nodes 1 or 2 rarely. Tillering weak, shoot soft, 5 leaves.

Plot 2. Height 23 inches, leafy broad blades, long internodes 4 inches, 3 nodes. Good fibrous roots, $5\frac{1}{4}$ leaves. Ear well forward. Stem firm.

Plot 3. Height 24 inches, leaf broad, no colour difference. 3 to 4 tillers, 2 to 3 nodes. Roots better than 5. $5\frac{1}{4}$ leaves, rows not visible.

Plot 4. Height 21. Colour good, leaf spreading in habit; 2 to 3 nodes, internode 3 inches. Good roots. As much leaf as 2.

Plot 5. Height 19 inches. Leaf broad, 2 to 3 tillers. Good colour. Only one node. Stem slight. Roots fair, drill rows visible.

August 18th.

The most marked difference in ripening was the delay of a few days in the No Potash plot (Plot 3).

Timberland Fen, Walcott. 1924.

May 25th.

No difference visible.

June 12th.

Plot 1. Very good plot. Colour good; broad leaf, no drill rows visible; 5 to 6 tiller; 5 leaves. Roots only moderately fibrous, 2 to 3 nodes with long internodes.

Plot 2. Better in all ways than 1. Very firm straw. Few shrivelled leaves. Ear nearly breaking.

Plot 3. As 2, but a little more upright in habit, less spreading. Thinner straw. Ear less marked. Excellent in growth and colour. Roots equal to 2.

Plot 4. Very similar to 3, with poorer roots.

Plot 5. Very much as for 1. The most uneven of all.

General.—Potash and phosphate shortage show slightly.

Cawkwell.

June 13th.

Plot 1. Thin, drill rows visible, tips of leaves dying off, roots poor and coming off coleoptile. Soft stem and short. 3 tillers.

Plot 2. Not very good plot, leaves dying at tip. Less vigorous than plot 4. Stem thin; starting to shoot; 4 tillers. Roots fair.

Plot 3. Marked falling-off from 4. Taller than Plots 1 or 5, but no more leaf. Leaves $3\frac{1}{2}$, one node only. Soft stem. Roots poor. Colour good.

Plot 4. The best of the series, colour good. Broad leaf, 1 node only, but longest stem. 3 to 4 leaves, 4 tillers, roots not very fibrous.

Plot 5. Colour good, 3 to 4 leaves, narrow, not yet shooting, nodes nil, tillers 3. Roots poor.

Harper Adams Agricultural College. 1924.

May 30th.

Wet weather has made it impossible to judge between the different treatments.

June 18th.

Plot 1. Uneven plot. Some tillers dying off. Drill rows visible. Standing very straight. Leaves yellowing markedly. Stem soft; 3 nodes.

Plot 2. Colour very good, growth good, 4 nodes; leaves all green. Roots well developed. Stem still soft.

Plot 3. Less hardy appearance all round than 2. Narrower in leaf. Yellowish colour in leaf.

Plot 4. Less leafy and tall than preceding. Light in colour. Drill rows visible. Stem soft.

Plot 5. Drill rows visible, leaf poor; colour yellow, similar in appearance to 4; better than 1.

Eyton. 1924.

May 24th.

No difference visible.

June 19th.

Plot 1. Poor in leaf and less mature than 5. Turning yellow, short in leaf. No shooting visible; soft in stem. Drill rows visible.

Plot 2. Appears the leafiest of all. Greener than 1. One whole above the ear in sheath. Stronger than 1 in stem.

Plot 3. Colour good as 2. Tillering 2, leaf medium broad. Roots only moderate.

Plot 4. Not as dark as 3, otherwise very much the same. Leaf a little narrower. Some ears already out.

Plot 5. Drill rows visible. Evidence of dead tillers.

Chiselborough, Stoke-under-Ham. 1924.

May 27th.

Plot 2 the best. Plots 1 to 5 show little difference.

June 23rd.

Plot 1. Quite a fair plot, but behind the others. Weak in straw, poor in tillering.

Plot 2. The best plot in all ways, straw leaf and tiller; and good colour 5-10 per cent. ears out.

Plot 3. Growth good, green, leaf well developed. More ears shot than other deficiency plots. Except for ear development not better than 4.

Plot 4. Glauous in colour. Growth good. Slightly yellow in lower leaves. More leaf than 1. Ears emerging.

Plot 5. Poor in tillering, yellow in colour. Awns just emerging; slender straw.

THE INSTITUTE OF BREWING RESEARCH SCHEME.

THIRD REPORT ON THE INFLUENCE OF SOIL, SEASON AND MANURING ON THE QUALITY AND GROWTH OF BARLEY OF THE 1924 CROP AS INDICATED BY THE MALTS MADE THEREFROM.

By H. M. LANCASTER.

Details of the centres where the barleys were grown are given in Sir John Russell's report (this *Journ.*, 1925, p. 548).

For the purposes of this report, it may not be out of place to repeat the explanation of the malting process which is similar to that employed in former years.

Three hundred grms. of the dried barley of each experimental growth were weighed into a stocking of net material which allows free passage of air and steeped for fifty-four hours at a temperature of 52°–56° F. in the ordinary cistern.

This year, the barleys, ninety-eight samples in all, were steeped together and floored for nine days at temperatures of 57°–65° F., and dried and cured with the "piece" of malt with which they were malted.

Three hundred grms. of the barley of each control "piece" were treated in exactly the same way as the experimental lots in a stocking to serve as a control. The average of the "pieces" and controls were compared and the results corrected accordingly.

Four maltings were carried out of each barley—the dates of steeping being 13th March, 20th March, 3rd April and 10th April. The first three control pieces were Indian barley and the fourth Brewing Chilian barley. The average malting loss of the four pieces was 8 per cent., and that of the four controls 10 per cent. The average extract, calculated on dry matter, of the four pieces was 92.2 lb. and that of the four control 91.2 lb.

The figures for extract and malting loss have, therefore, been corrected as follows:—

Extract.—One pound has been added to the analytical figures.

Malting loss.—Is reduced in the proportion of 8 to 10.

Even with this correction the brewers' extract is lower in the stocking malting than in the bulk maltings, which were carried out by Messrs.

Hugh Baird & Sons, Ltd., and Gilstrap, Earp & Co., Ltd., the figures for raw malt being:—

Barley.	Extract on dry malt.		
	Stocking.	Ordinary.	Difference.
Walcott	98.6	101.1	2.5
Orwell Park	99.6	101.5	1.9
Dunmow	99.9	101.3	1.4
Wellingore	99.9	101.0	1.1

It is probable that another day's flooring would have increased the extracts especially in the case of the coarser barleys. No figures for malting loss on the bulks have been received.

In fact malt made in small quantities in stockings is not so satisfactory as malt made on the floors in the ordinary way and, owing to the fact that the former is only rubbed over a sieve and the latter polished on a malt screen, it has not such an attractive appearance. This fact was emphasised when the malts were judged and the difference in appearance between malts made in bulk and bags was remarkable. This difference, however, was entirely eliminated after the stocking malts had been polished by friction.

Brewers' extracts are calculated in the accompanying tables to dry malt for comparison, and back to the extract obtained from 448 lb. of raw barley. The latter figure is, of course, dependent on the extract obtained, the original moisture of the barley and the malting loss.

The actual value of 448 lb. raw barley is obtained by taking the valuation of the malt—less 25s. for freight on barley and malt, malting expenses and profit on malting, and referring back the amount of malt made from the 448 lb. raw barley. For instance, No. 18 barley had a moisture content of 20.8 per cent. and showed a malting loss of 7.9 per cent. Calculating 2 per cent. of moisture in malt, and without allowing for any loss of dry matter on sweating the barley, this shows a loss of 1 per cent.

which in this case depreciates the value of the barley by about 1s.

In the case of No. 56, with only 17·1 per cent. of moisture and a malting loss of 9·3 per cent., there is an increase of about 2 per cent.

It must be remembered that the reason for malting the barleys is to ascertain whether the malt bears out the promise given by the barley which is assessed by the judges on empirical valuation only. When judging and valuing the malts, the judges have the malt analyses before them.

In brief, the values attributed to barleys are those which the judges would have paid for similar barleys on the open market, and the values attributed to malts are those which the judges would have obtained for similar malts.

On the basis of the system adopted, and already described, which is considered the best available, for malt valuation, the market value of the barley was too high in the cases of Wye, Wellingore, Dunmow, Rothamsted

and Woburn. Eyton, Newport and Louth were undervalued, the last-named for the third year in succession. In the cases of Wallcott, Porlock, Norwich, Chiselboro and Nacton (Orwell Park), the valuations of the barley were borne out by those of the malts, though in the last-mentioned case one distinctly poorer malt depreciated the average malt value.

On the same basis, the Wye barleys were overvalued by no less than 18s. per qr., those from Eyton-on-Severn were undervalued by 13s. per qr., and out of the barleys from thirteen stations the valuations were borne out only in about six cases. It must be remembered that in the autumn of 1924 there was keen competition for fine barleys and sellers on many of the country markets thought in half-crowns instead of shillings or sixpences, but making all allowances for this, it is impossible to consider the values without concluding that empirical valuation of barley may be misleading. Further research in this direction is obviously necessary.

APPENDIX.

MALTING RESULTS.

By H. M. LANCASTER.

ANALYTICAL RESULTS.

By H. LLOYD HIND, B.Sc., F.I.C.

FOLLOWING the course adopted in the Second Report published in March (this *Journal*, 1925, 104), the results of the analytical determinations usually made for the technical valuation of Barley and Malt are published with the present report on the Barleys of 1924 and the Malts made from them. The valuations of the Barleys and Malts and the figures obtained for malting loss and for the actual value of 448 lb. raw Barley are incorporated in the tables.

The malt analyses have in all cases been conducted by the standard methods laid down by The Malt Analyses Committee of the Institute.

Many other analytical determinations have been made both on the barleys and malts, but it is considered advisable to hold over any detailed discussion of the results obtained until those concerning the four years' series of experiments can be collated and discussed as a whole. The barleys grown in 1925 complete the series extending over four years.

Sir John Russell has indicated in his Third Report (this *Journal*, 1925, 518), that very important observations on the effect of various manurial treatments have already been made, and that important conclusions may be expected as a result of the consideration as a whole of the cultural trials extending over the four years, 1922-1925, and the analytical examination and valuation of the barleys and malts obtained.

The plot numbers refer as in previous reports to the following manurial treatments:—

- (1) No Manure.
- (2) Complete Artificial.
- (3) Artificial without Potash.
- (4) Artificial without Phosphate.
- (5) Artificial without Nitrogen.

No.	Plot.	Barley.						Malt.						The averages of valuations are taken to the nearest shilling.
		Moisture per cent.	1,000 corn weight (grms.) dry.	Nitrogen per cent. on dry.	Malting loss per cent. on dry.	Extract calculated to 448 lb. raw.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic Power	Lutner.	Cold water	Extract per cent.	Market valuation by sub-committee.
														Barley, 448 lb., Nov., 1924.
														Malt, 336 lb., Dec., 1924.
														Value of 448 lb. raw Barley dressed, based on valuation of malt

W. HASLER, DUNMOW, ESSEX.

Medium to heavy clay loam.

9	1	19.44	39.1	1.564	9.6	95.0	2.18	97.9	6.7	26.0	18.9	67/-	80/-	55/-
10	2	17.28	40.0	1.447	9.5	98.9	1.94	98.9	6.1	26.0	19.0	68/-	80/-	56/-
11	3	18.24	39.2	1.438	9.6	97.4	2.34	99.8	5.5	24.5	19.9	70/-	85/-	60/-
12	4	18.12	40.4	1.425	9.1	98.3	1.92	99.0	5.2	25.0	19.7	70/-	85/-	61/-
13	5	16.94	41.3	1.400	9.1	99.6	2.18	98.9	4.5	24.5	19.4	70/-	85/-	62/-
Average		18.00	40.0	1.463	9.4	97.8	2.11	98.9	5.7	25.2	19.4	69/-	83/-	59/-

No.	Plot.	Barley.						Malt.						The averages of valuations are taken to the nearest shilling.		
		Moisture per cent.	1,000 corn weight (grms.) dry.	Nitrogen per cent. on dry.	Malting loss per cent. on dry	Extract calculated to 448 lb. raw		Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic Power Lintner°.	Cold water Extract per cent.		Market valuation by sub-committee.		
														Barley, 448 lb., Nov., 1924.	Malt, 336 lb., Dec., 1924.	Value of 448 lb. raw Barley dressed based on valuation of malt.

A. E. DAVY, CAWKWELL, SCAMBLESBY, LOUTH, Lincs.

Chalk wolds.

14	1	20.32	36.9	1.266	8.6	97.2	1.76	100.2	4.0	25.0	17.5	65/-	95/-	69/-
15	2	20.54	37.2	1.199	8.1	97.9	1.62	100.3	4.0	23.0	18.1	65/-	95/-	70/-
16	3	19.94	38.0	1.253	8.2	98.8	1.80	100.7	4.2	23.5	17.5	65/-	95/-	70/-
17	4	20.49	37.1	1.204	8.0	98.0	1.98	100.4	4.5	24.0	18.1	63/-	95/-	70/-
18	5	20.85	37.7	1.194	7.9	97.5	2.00	100.4	4.0	23.0	17.9	63/-	95/-	68/-
Average		20.43	37.4	1.223	8.2	97.9	1.83	100.4	4.1	23.7	17.8	64/-	95/-	70/-

G. H. NEVILLE, WELLINGORE, Lincs.

Lincoln Heath, Light loam.

19	1	17.88	39.2	1.424	8.8	97.5	1.94	97.7	9.5	24.5	20.5	72/-	80/-	56/-
20	2	17.82	39.3	1.404	9.6	97.7	1.92	98.7	9.5	19.0	22.4	71/-	80/-	56/-
21	3	18.00	40.9	1.403	8.7	99.3	1.90	99.5	8.5	23.0	21.6	70/-	80/-	56/-
22	4	18.21	38.8	1.449	8.6	99.2	1.66	99.4	7.2	23.0	21.7	70/-	80/-	56/-
23	5	18.25	40.3	1.400	8.6	98.8	1.74	99.0	9.5	22.0	21.4	72/-	80/-	56/-
23A	*	16.76	38.9	1.424	10.6	97.9	1.68	98.8	9.0	26.0	21.8	72/-	80/-	56/-
Average	19-23	18.03	39.5	1.421	9.1	98.4	1.83	98.9	8.8	23.5	21.9	71/-	80/-	56/-

E. CRAIG TANNER, EYTON-ON-SEVERN, SHROPSHIRE.

Trias red medium loam, gravelly.

24	1	17.75	39.2	1.388	8.6	98.8	2.10	98.8	5.2	25.5	19.0	66/-	103/-	80/-
25	2	17.46	39.6	1.374	8.3	99.5	1.78	99.1	5.2	25.0	19.3	66/-	103/-	80/-
26	3	17.54	40.0	1.361	8.0	100.8	1.63	99.6	5.0	24.5	19.1	66/-	100/-	77/-
27	4	17.39	40.0	1.328	7.6	101.7	1.60	100.0	5.2	22.0	18.7	66/-	103/-	81/-
28	5	17.76	39.2	1.356	8.4	100.3	1.78	99.8	5.2	24.5	18.9	70/-	103/-	80/-
Average		17.58	39.6	1.361	8.2	100.2	1.80	99.5	5.2	24.3	19.0	67/-	102/-	80/-

R. A. CLARKE & SONS, CHISELBOROUGH, STOKE-UNDER-HAM, SOMERSET.

Light sandy soil.

29	1	20.22	36.4	1.461	8.5	97.0	2.18	99.4	4.7	25.5	18.2	74/-	100/-	74/-
30	2	19.87	37.4	1.403	8.5	96.3	2.10	98.7	5.5	26.0	19.0	74/-	103/-	78/-
31	3	19.94	38.0	1.510	8.8	95.3	1.86	98.1	5.5	25.0	19.1	74/-	95/-	70/-
31A	4	20.03	38.1	1.495	9.0	95.1	1.86	98.1	5.0	23.0	18.9	74/-	100/-	74/-
31B	5	20.06	37.0	1.451	8.5	95.8	1.86	98.3	4.8	24.0	18.7	68/-	100/-	75/-
Average		20.02	37.4	1.464	8.7	96.7	1.97	98.5	5.1	24.7	18.8	73/-	100/-	74/-

* Surface sown after Beet residues.

No.	Plot.	Barley.						Malt.					The averages of valuations are taken to the nearest shilling.		
		Moisture per cent.	1,000 corn weight (grms.) dry.	Nitrogen per cent. on dry.	Malting loss per cent. on dry.	Extract calculated to 448 lb. raw.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic Power Lintner ² .	Cold water Extract per cent.	Barley, 448 lb., Nov., 1924.	Malt, 336 lb., Dec., 1924.	Value of 448 lb. raw Barley dressed, based on valuation of malt.	Market valuation by sub-committee.

RT. HON. E. G. PRETYMAN, ORWELL PARK, MARTLESHAM, SUFFOLK.

Light sand.

32	1	19.32	42.7	1.591	9.6	94.6	2.24	97.5	7.5	29.0	22.4	67/-	93/-	67/-
33	2	18.44	39.0	1.407	10.4	97.1	2.20	99.9	7.2	31.0	22.7	70/-	93/-	67/-
34	3	19.26	41.2	1.631	9.0	96.0	2.22	97.9	7.0	32.0	21.3	64/-	80/-	55/-
35	4	18.44	38.2	1.433	9.0	97.6	2.10	98.8	6.5	25.5	22.6	70/-	93/-	69/-
36	5	19.10	42.1	1.521	9.4	96.7	2.30	98.9	6.5	29.0	22.7	67/-	93/-	68/-
Average		18.91	40.6	1.517	9.5	96.4	2.27	98.6	6.9	29.3	22.3	68/-	90/-	65/-

C. BEMBRIDGE, WALCOTT, Lincs.

Black Fen.

38	1	18.50	42.8	1.581	9.9	96.4	2.22	98.6	6.5	31.0	21.2	63/-	90/-	65/-
39	2	18.13	44.4	1.586	10.6	95.4	2.42	97.7	6.5	33.5	20.4	63/-	90/-	65/-
40	3	18.30	43.1	1.613	11.2	94.6	1.94	98.0	6.5	26.5	21.3	63/-	90/-	64/-
41	4	18.36	42.4	1.560	10.4	94.4	1.84	96.8	7.0	30.0	20.8	63/-	90/-	65/-
42	5	18.44	43.3	1.575	11.3	93.1	2.00	96.8	7.5	28.5	21.5	63/-	85/-	59/-
Average		18.35	43.2	1.583	10.7	94.8	2.08	97.6	6.8	29.9	21.0	63/-	89/-	64/-

NORFOLK EXPERIMENTAL STATION, NEWTON ST. FAITH'S, NORWICH.

Light loam, overlying gravel.

43	1	18.16	33.0	1.334	10.1	96.0	2.33	97.8	5.5	25.0	19.0	68/-	93/-	73/-
44	2	18.42	34.2	1.286	9.6	98.3	2.30	99.4	5.0	21.5	19.7	72/-	100/-	76/-
45	3	18.70	32.8	1.363	9.7	95.4	1.90	97.5	6.0	26.0	19.2	72/-	90/-	65/-
46	4	17.28	33.7	1.324	10.0	97.9	2.24	98.6	5.5	24.5	19.2	72/-	97/-	73/-
47	5	18.18	34.5	1.289	10.5	95.2	1.84	97.6	5.3	24.0	19.0	68/-	97/-	72/-
Average		18.15	33.6	1.319	10.0	96.6	2.12	98.2	5.5	24.2	19.2	70/-	95/-	72/-

HARPER ADAMS AGRICULTURAL COLLEGE, NEWPORT, SALOP.

Sandy loam.

53	1	17.12	39.2	1.508	9.3	99.5	2.10	99.3	7.0	31.5	21.5	50/-	80/-	57/-
54	2	17.86	39.1	1.624	10.4	96.5	2.00	98.5	7.0	32.5	22.1	50/-	80/-	55/-
55	3	16.82	40.6	1.631	9.7	98.1	1.96	98.5	8.0	33.5	22.3	50/-	80/-	56/-
56	4	16.30	39.8	1.506	9.8	99.9	1.98	99.1	8.0	32.0	22.0	50/-	80/-	57/-
57	5	16.84	38.6	1.514	9.5	99.3	1.90	99.1	8.0	30.0	22.4	50/-	80/-	57/-
Average		16.99	39.5	1.557	9.7	98.6	1.99	98.9	7.6	31.9	22.1	50/-	80/-	56/-

No.	Plot.	Barley.						Malt.						The averages of valuations are taken to the nearest shilling.		
		Moisture per cent.	1,000 corn weight (grms.) dry.	Nitrogen per cent. on dry.	Malting loss per cent. on dry.	Extract calculated to 448 lb. raw.		Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic Power Lintner°.	Cold Water Extract per cent.		Market valuation by sub-committee.		
														Barley 448 lb. Nov., 1924.	Malt, 336 lb. Dec., 1924.	Value of 448 lb. raw Barley dressed, based on valuation of malt.

SOUTH EASTERN AGRICULTURAL COLLEGE, WYE, KENT.

Loam over chalk.

58	1	19.50	40.5	1.741	10.5	93.6	2.18	97.6	6.2	32.0	19.5	74/-	85/-	58/-
59	2	20.12	39.2	1.708	9.6	93.9	1.84	97.6	5.5	33.0	20.2	74/-	82/-	56/-
60	3	20.72	38.8	1.748	10.9	91.3	2.14	97.2	7.5	30.5	19.9	74/-	82/-	54/-
61	4	21.04	39.1	1.750	9.7	93.1	2.08	98.1	7.5	28.0	21.0	74/-	82/-	54/-
62	5	21.58	39.4	1.592	9.6	93.0	1.84	98.2	6.5	30.5	20.6	74/-	85/-	57/-
Average		20.59	39.4	1.708	10.1	93.0	2.02	97.7	6.6	30.8	20.2	74/-	83/-	56/-

T. H. RAWLE, PORLOCK, SOMERSET.

Stone brash.

63	1	17.85	38.6	1.295	8.5	100.0	2.34	99.4	5.5	23.0	19.7	87/-	108/-	85/-
64	2	16.64	39.4	1.266	8.2	101.8	1.76	99.8	5.5	22.0	19.9	90/-	110/-	89/-
65	3	17.60	38.9	1.326	8.5	99.4	1.74	98.8	5.5	20.0	20.3	90/-	110/-	88/-
66	4	17.28	37.2	1.268	8.4	101.3	2.06	100.2	5.0	22.0	20.0	90/-	112/-	90/-
67	5	16.81	39.8	1.359	9.1	100.2	1.84	99.5	6.0	21.0	20.6	87/-	108/-	86/-
Average		17.24	38.8	1.303	8.5	100.6	1.95	99.5	5.5	21.5	20.1	89/-	110/-	88/-

WOBURN EXPERIMENTAL FARM, BEDS.

Sandy loam.

68	1	19.26	37.6	1.230	10.2	98.0	1.94	101.4	5.0	21.0	19.4	80/-	103/-	76/-
69	2	18.75	37.3	1.161	10.4	96.8	1.82	99.9	5.2	19.0	20.0	90/-	104/-	78/-
70	3	18.56	35.8	1.173	9.7	97.8	1.76	99.8	5.5	18.0	20.8	90/-	106/-	81/-
71	4	18.57	39.6	1.259	10.3	97.0	1.86	99.6	5.5	22.0	19.2	80/-	105/-	79/-
72	5	18.76	38.6	1.310	10.5	95.8	1.86	99.0	5.5	22.0	19.8	72/-	103/-	77/-
Average		18.78	37.8	1.227	10.2	97.1	1.85	99.9	5.3	20.5	19.8	82/-	104/-	78/-

ROTHAMSTED EXPERIMENTAL STATION, HARPENDEN, HERTS.

Malting Barley set

Heavy strong soil, clay with flints.

81	1	16.10	40.6	1.620	9.8	97.6	1.84	96.7	7.0	27.0	22.8	60/-	80/-	57/-
82	2	17.00	42.4	1.517	10.2	48.0	2.00	98.0	7.0	25.5	21.8	64/-	80/-	56/-
83	3	17.28	42.2	1.540	9.2	48.2	2.15	98.0	7.2	28.0	21.2	64/-	80/-	57/-
84	4	17.32	41.5	1.525	9.7	97.4	1.56	97.8	6.8	24.5	21.7	64/-	80/-	56/-
85	5	17.06	42.2	1.611	10.2	95.9	1.74	96.5	7.5	25.5	23.1	64/-	80/-	56/-
86	(KCl)	17.18	41.2	1.479	8.8	98.6	1.66	97.9	6.8	24.5	22.1	64/-	82/-	59/-
87	(AmCl)	16.83	42.4	1.495	9.7	98.5	2.13	98.3	7.0	26.5	21.7	64/-	82/-	59/-
Average		16.95	41.8	1.563	9.7	97.9	1.86	97.4	7.1	26.1	22.1	63/-	80/-	57/-

No.	Plot.	Barley.						Malt.						The averages of valuations are taken to the nearest shilling.		
		Moisture per cent.	1,000 corn weight (grms.) dry.	Nitrogen per cent. on dry.	Malting loss per cent. on dry.	Extract calculated to 448 lb. raw.		Moisture per cent.	Extract per 396 lb. dry.	Colour.	Diastatic Power.	Lintner?.	Cold Water Extract per cent.	Market valuation by sub-committee.		
														Barley 448 lb. Nov., 1924.	Malt, 336 lb. Dec., 1924.	Value of 448 lb. raw Barley dressed, based on valuation of malt

OTHER ROTHAMSTED BARLEYS.

Permanent Barley Plots.*

109	7-1	18.06	34.4	1.332	10.5	94.9	2.68	97.1	12.5	20.0	22.5	Black	Not	—
110	7-2	19.78	41.2	1.541	10.1	93.3	2.24	97.4	12.5	25.0	22.1	60/-	valued	—
112	6-2	18.42	34.8	1.324	9.8	96.7	2.20	98.5	13.0	19.5	22.8	Black		—

Great Harpenden Field.

Silicate set.

119	H. 11 & 35	17.50	40.3	1.548	8.9	98.6	2.00	98.4	6.0	27.0	22.3	65/-	85/-	62/-
120	H. 4 & 28	17.27	38.7	1.505	9.0	99.1	2.02	98.8	7.0	23.0	22.0	65/-	82/-	59/-
121	H. 12 & 29	17.57	40.0	1.537	9.0	97.9	1.92	97.9	6.5	26.0	22.1	65/-	85/-	62/-
122	H. 10 & 30	17.20	40.3	1.509	9.4	98.9	2.28	98.8	7.0	27.5	21.4	65/-	90/-	67/-
Average		17.38	39.8	1.525	9.1	98.6	2.05	98.5	6.6	25.9	22.0	65/-	86/-	63/-

Nitrogen set.

124	N. 4 & 13	17.28	40.9	1.503	9.1	98.9	2.18	98.7	5.5	24.5	20.0	66/-	96/-	73/-
125	N. 5 & 12	16.53	40.7	1.410	8.7	101.0	1.99	99.2	5.5	22.0	20.3	66/-	95/-	73/-
126	N. 6 & 11	17.00	41.3	1.509	9.6	98.9	2.20	98.8	6.5	24.5	21.2	66/-	95/-	72/-
127	N. 7 & 10	16.96	42.0	1.513	8.6	98.9	2.02	97.7	6.5	23.5	20.9	66/-	95/-	73/-
128	N. 3 & 14	16.92	42.1	1.574	8.9	97.1	2.10	96.3	5.5	28.0	21.3	63/-	90/-	68/-
130	N. 8 & 1	16.74	40.0	1.499	8.7	99.8	2.16	98.5	5.5	27.5	20.0	66/-	96/-	74/-
Average		16.92	41.7	1.501	8.9	99.1	2.13	98.2	5.8	25.0	20.6	66/-	95/-	72/-

* The manurial treatments of the Rothamsted plots were as follows—

Plot 7.1.... No manure since 1871.
 „ 7.2.... Dung since 1852.
 „ 6.2.... Coal ashes.

Silicate set—

H. 11 & 35 Basal (1 cwt. Sulphate of Potash and 107 lb. Sulphate of Ammonia).
 H. 4 & 28 „ with Phosphate.
 H. 12 & 29 „ „ Silicate.
 H. 10 & 30 „ „ Phosphate and Silicate.

Nitrogen set—

N. 4 & 13 „ „ 1 cwt./acre Sulphate of Ammonia.
 N. 5 & 12 „ „ 2 „ „
 N. 6 & 11 „ „ 1 „ „ Muriate
 N. 7 & 10 „ „ 2 „ „
 N. 3 & 14 (2 cwt. Super. and 1 cwt. Sulphate of Potash).
 N. 8 & 1 „ with Urea.

No.	Plot.	Barley.					Malt.					The averages of valuations are taken to the nearest shilling.		
		Moisture per cent.	1,000 corn weight (grms.) dry.	Nitrogen per cent. on dry.	Malting loss per cent. on dry.	Extract calculated to 448 lb. raw.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic Power Lintner°.	Cold water Extract per cent.	Barley, 448 lb., Nov., 1924.	Malt, 336 lb., Dec., 1924.	Market valuation by sub-committee.

NATIONAL INSTITUTE OF AGRICULTURAL BOTANY.

Barleys grown at Newton St. Faith's, Norfolk.

166	Beaven's 1920	19.50	33.3	1.279	9.4	94.2	2.34	97.6	5.2	26.0	18.9	78/-	100/-	74/-
166c	Control (Archer)	19.32	32.0	1.328	10.2	93.5	2.14	97.5	6.5	23.5	19.3	73/-	90/-	64/-
167	Webbs "B"	19.08	33.3	1.371	10.0	95.9	2.16	98.8	5.2	22.0	18.9	74/-	92/-	66/-
167c	Control (Archer)	18.91	32.2	1.426	10.6	93.2	2.08	96.6	6.3	27.0	19.4	71/-	93/-	66/-
169	Cambridge 59/120	19.11	33.2	1.472	9.5	95.7	2.06	98.1	6.0	23.0	18.9	75/-	91/-	66/-
169c	Control (Archer)	19.48	30.8	1.380	10.2	93.4	1.98	97.1	5.7	24.0	18.7	74/-	88/-	61/-

THE INSTITUTE OF BREWING RESEARCH SCHEME.

FOURTH REPORT ON THE EXPERIMENTS ON THE INFLUENCE OF SOIL, SEASON AND MANURING ON THE QUALITY AND GROWTH OF BARLEY, 1925.

BY SIR E. JOHN RUSSELL, O.B.E., D.Sc., F.R.S. (*Director, Rothamsted Experimental Station, Harpenden.*)

As was foreshadowed in the last report, the series of experiments dealt with in this report was in the main brought to a conclusion at the end of 1925, only a few centres being carried on in 1926, and these only where some special point needed further investigation. The 1926 results are not yet available, and in consequence the full report on the series cannot yet be given; the present report is, like its predecessors, in the nature of an interim report, dealing mainly with the results of 1925, but directing attention to any differences between these and former results.

The object of the experiment is two-fold:—

1. To provide farmers with information as to how they can better satisfy the requirements of the maltster and brewer as to quantity and quality of produce.

2. To obtain analytical and other chemical and physical data in regard to the quality of barley and its behaviour on malting: in this way to test the value of current analytical methods and to study the relationship of chemical composition of barley to malting and brewing value.

The plan of the experiment is to grow barley at a number of different centres on uniform manurial schemes which include the following:—

1. No manure.

2. Complete artificials: 1 cwt. sulphate of ammonia, 3 cwt. superphosphate, $1\frac{1}{2}$ cwt. sulphate of potash per acre.

3. Artificials without potash: 1 cwt. sulphate of ammonia, 3 cwt. superphosphate per acre.

4. Artificials without phosphate: 1 cwt. sulphate of ammonia, $1\frac{1}{2}$ cwt. sulphate of potash per acre.

5. Artificials without nitrogen: 3 cwt. superphosphate, $1\frac{1}{2}$ cwt. sulphate of potash per acre.

The variety tested is Plumage Archer. The same lot of seed is used throughout

all the experiments, being specially selected by Mr. W. Hasler, of Dunmow.

This year a sixth plot was added receiving sulphate of ammonia.

6. 1 cwt. sulphate of ammonia per acre.

The list of centres for this year was:—
Eastern Side

1. Rothamsted Experimental Station, Harpenden, Herts.

2. Beds. Woburn Experimental Farm, Dr. J. A. Voelcker.

3. Kent, Wye. South-Eastern Agricultural College, R. M. Wilson, Esq., Principal.

4. Essex, Dunmow. W. Hasler, Esq., Barnston Lodge Farm (G. Bellfield, Esq.).

5. Norfolk Experimental Station, Sprowston, F. Rayns, Esq.

6. Lines, Wellingore, G. H. Neville, Esq.

7. E. Yorks., Beverley. J. H. Spilman, Esq., Gardham Farm.

Western Side

8. Shropshire, Eytton-on-Severn. E. Craig-Tanner, Esq.

9. Shropshire, Newport. Harper Adams Agricultural College, Dr. C. Crowther.

10. Stoke-under-Ham. R. A. Clarke & Sons, Chiselborough.

11. Somerset, Porlock. T. H. Rawle, Esq., Court Place.

The Season.—The winter of 1924-25 was remarkable for the water-logged condition of the land throughout the winter cultivation period, especially on heavy soils.

March brought dying winds and frosts, and enabled barley to be sown at Rothamsted on stale furrows on a good tilth (March 19th to 31st).

April was cold and sunless, but barley appeared better than was expected. In the second week in May the temperature rose and growth was rapid. June and the first half of July brought drought, but the barley stood this well, though it was shorter in the straw in consequence. Maturity was hastened.

Harvest was impeded by wet weather at

the end of July and throughout August. The rainfall at Rothamsted is given in Appendix II.

The Results.—There had been no cross cropping, and the results are collected in Table I. Of the 59 tests recorded, one at Dunmow is incomplete, and must therefore be disregarded, because the crop was badly laid and could not be properly harvested. One plot at Wye—the unmanured—gives an abnormally high yield, as do one or two plots at the Harper Adams College, one at Chiselborough and one at Rothamsted. The remaining tests—90 per cent. of the total—give results agreeing with the earlier ones and affording strong confirmation of the correctness of the conclusions drawn from them.

A sixth plot had been added receiving sulphate of ammonia only, to test last year's deduction that this was the most effective of the three fertilisers tried. The advantage of this additional plot is that two different comparisons can be made at each centre to discover the effects of the separate fertilisers. Thus the effect of nitrogenous fertilisers may be obtained from

Plot 2-Plot 5 (Complete artificials—no nitrogen).

Plot 6-Plot 1 (Nitrogen only—no manure).

The influence of the nitrogenous manure has been practically the same as in previous years. On the average the addition of 1 cwt. sulphate of ammonia increased the yield of total grain by 7·4 bushels per acre and of dressed grain by 7·1 bushels. The increase ranged at the various centres from over 10 bushels at Wellingore and at Eyton to one bushel at Porlock.

The results are :—

GAINS DUE TO SULPHATE OF AMMONIA—BUSHELS PER ACRE.

	In presence of Minerals		Without Minerals	
	Total	Dressed	Total	Dressed
Rothamsted ..	6·25	—	11·50	—
Woburn ..	—2·40	—2·40	3·90	4·10
Wye ..	3·00	5·50	—	—
Dunmow*	11·23	10·66	5·13	6·25
Sproawton ..	4·60	—	5·34	—
Wellingore ..	10·59	9·75	4·33	4·58
Eyton ..	11·43	11·18	15·00	18·82
Harper Adams ..	15·86	15·07	7·00	16·14
Chiselborough (Stoke)	6·00	6·00	11·50	12·00
Porlock ..	1·20	1·20	—2·28	—2·28
Mean ..	7·38	7·12	6·94	7·09

* Complete manured plot badly laid
no Potash plot. Calculations based on

It is remarkable that the average increase given by sulphate of ammonia alone is the same whether phosphate and potash are given or not.

The effect of phosphate has been considerably more pronounced than usual. The increase is shown in both sets of plots, and at some of the centres even the numerical values are nearly the same, which would not necessarily be expected. In presence of nitrogen and potassium the phosphate has given gains of 7 to 10 bushels per acre at the Harper Adams College and Eyton, and of 3·4 bushels at Rothamsted, Norwich, Porlock and Wellingore; on the other hand it gave no increased crop at Chiselborough or Woburn; indeed, as last year, it appeared to depress the crop at Woburn. In absence of potassium the results are substantially the same except at the Harper Adams College, where there was no gain, but the comparison involves the apparently abnormal plot, and may therefore not be valid. This is a record of effectiveness for phosphates: individual centres have shown responses of this order before, but never so many in one season. A detailed comparison is being made between the weather conditions of this season, and those of its predecessors, to discover, if possible, the reason for this marked effectiveness.

Sulphate of potash, on the other hand, was without effect at any centre except Harper Adams and Chiselborough, where it increased the yield by 2½-4 bushels. There have been no clear instances this year of depression of crop by potassic fertilisers which was so marked last year. The results are set out below :—

BUSHELS PER ACRE.
Increase + Decrease -

	Phosphate.		Potash.	
	Total Grain. With K and N	Total Grain. With N only.	Total Grain. With P and N.	Total Grain. With N only
Rothamsted ..	4·12	—	0·12	—
Woburn ..	3·50	2·20	1·80	3·90
Wye ..	1·90	—	0·10	—
Sproawton ..	3·20	1·10	0·20	0·70
Wellingore ..	3·75	6·67	0·92	2·00
Eyton ..	7·77	9·39	0·18	1·80
Harper Adams ..	10·72	3·21	4·50	9·43
Stoke ..	8·20	—	2·50	—
Porlock ..	3·12	3·30	1·29	1·32
Average ..	2·58	3·76	0·33	0·39

Effect of Manuring on Valuation.—Interest centred this year on two problems :—

1. Seeing that superphosphate had improved the yield, would it also improve the quality?

2. How would the plot supplied with sulphate of ammonia only compare with the plots receiving potassic and phosphatic fertilisers in addition?

The effect of superphosphate was, as usual, negligible on the valuation. Only at Wellingore was there any loss by omitting it, and there it amounted to 3s. per quarter of 448 lb.

Sulphate of potash also had but little effect; its omission lowered the valuation per quarter by 3s. at Wellingore, and 2s. at Eytton, but nowhere else.

The use of sulphate of ammonia alone was detrimental to value at Dunmow by 2s. and at Chiselborough by 3s. when compared with the complete manured, though not when compared with the unmanured. At Wellingore there is the great difference of 20s. per quarter, but this is so unusual and so unrelated to the other characteristics of the barley that it cannot without further evidence be attributed to the manure.

Apart from this the results show that the use of sulphate of ammonia has not adversely affected the quality and it has increased the yield. The comparison between the two possibilities, the expensive complete manure and the cheaper nitrogenous manure only is:

	Increase over plot without manure.			Gain after paying for fertiliser.
	Cost of manure per acre.	Bushels per acre.	Money value per acre.	
Complete manure	46 -	7.85 [†]	59 -	13 -
Sulphate of ammonia and superphosphate ..	24	7.2	54 -	30 -
Sulphate of ammonia only .. .	14 -	6.27*	43 -	29 -

* Omitting Rothamsted and Chiselborough.

† In this average Plot 3 was taken at Dunmow.

The Nitrogen Content of the Grain and Valuation.—Except at Wye and Porlock, the percentage of nitrogen in the grain is higher than in 1924. As before there is a close relationship between money value and nitrogen content, shown by the distinct tendency to place the higher money values

on the barleys of low nitrogen content, and the lower money values on barleys of high nitrogen content; this is the more remarkable as the judging is done without knowledge of the analysis. Arranged in order of nitrogen content the samples have been valued as follows:—

1925.							
			Average valuation shillings	Average per cent. of nitrogen.			
Average per cent. of nitrogen			per quarter.	1922.	1923.	1924.	
Porlock	1.18	78.0	—	—	1.30
Wye	1.38	60.0	—	—	1.71
Eyton	1.49	71.2	1.92	1.70	1.36
Wellingore	1.52	65.2	1.79	1.44	1.42
Stoke	1.55	68.7	—	1.50	1.46
Beverley	1.55	42.0	—	1.34	—
Harper Adams	1.58	55.0	—	—	1.56
Rothamsted	1.62	52.2	1.62	1.61	1.56
Sprowston	1.65	45.0	—	—	1.32*
Woburn..	2.01	37.0	1.95	1.71	1.23
Orwell Park	2.28	37.0	1.51	1.93	1.52

Grown at Newton St. Faith.

The Influence of Manuring on Nitrogen Content of the Grain.—It is characteristic of this season that the nitrogenous manures, however applied, almost always raised the percentage of nitrogen in the grain. The lowest nitrogen content was in barleys grown on the unmanured plots or with potassic and phosphatic fertilisers only.

The effect of phosphate and potassium was small, and is appreciable only when plot 5, which has both, is compared with the unmanured plot; at most centres the mixture has lowered the percentage of nitrogen.

Influence of Manuring on 1,000 Corn Weight.—The effect of manure is but small and not always in the same direction. Sulphate of ammonia alone either increases the weight or leaves it unaltered. Phosphate or potash added thereto usually reduces the

weight, but when both are given simultaneously the weight is not consistently reduced.

Effect of Ammonium Chloride on Barley.—In view of the beneficial effect of sulphate of ammonia on barley, special interest attaches to the results of the experiments at Rothamsted with muriate of ammonia, a fertiliser which can now, it is understood, be prepared more cheaply than sulphate of ammonia. In last year's report it was shown that muriate of ammonia caused an increase in either the valuation per quarter or the yield or both, so that the money value per acre to the farmer was increased while the nitrogen content of the grain was lowered. Apparently, therefore, this fertiliser would meet the needs of both farmer and maltster. The results this year point to the same conclusion.

Season.	Valuation of Barley per qr. of 448 lb.		N in grain per cent. of dry matter.	
	Ammonium Sulphate.	Ammonium Chloride.	Ammonium Sulphate.	Ammonium Chloride.
	s. d.	s. d.		
1922	31 0	36 0	1.647	1.602
1923	57 6	58 0	1.544	1.485
1924	63 6	64 0	1.517	1.495
1925	53 0	53 0	1.585	1.552

It has been observed that the muriate of ammonia increases the number of grains per acre reaching the standard of head corn; apparently it does this by increasing the

number of corns per head *i.e.*, reducing the number of infertile florets or of immature corns. The results have been in millions of grains per acre:—

YIELD IN MEASURED BUSHELS PER ACRE AND MONEY VALUE OF BARLEY PER ACRE.

Season.	Ammonium Sulphate.		Ammonium Chloride.		Differences in favour of Chloride as against Sulphate.
	Yield.	Money value per acre. Shillings.	Yield.	Money value per acre. Shillings.	
1922	36.0	136	35.7	156	20
1923	32.5	239	35.6	265	26
1924	29.8	238	29.7	249	11
1925	31.0	205	35.0	232	27

Millions per acre*.	No nitrogen.	Sulphate of ammonia.	Muriate of ammonia.	Excess of muriate over sulphate.
1922	17.1	18.9	19.8	0.9
1923	10.5	17.3	13.9	1.6
1924	12.0	16.7	17.0	0.3
1925	12.3	15.1	16.5	1.4

* Obtained by combining the yield with the weight per 1,000 corns.

TABLE III.

VALUATIONS AND PERCENTAGES OF NITROGEN IN THE VARIOUS SAMPLES. NITROGEN PER CENT. ON DRY BARLEY PRICE PER QUARTER.

	Rothamsted		Dunmow		Beverley		Luton		Wellingore		Porlock		Harper Adams		Stoke		Sprowston.		Woburn		Orwell Park.		Wye	
	Nitrogen %	Price.	Nitrogen %	Price.	Nitrogen %	Price.	Nitrogen %	Price.	Nitrogen %	Price.	Nitrogen %	Price.	Nitrogen %	Price.	Nitrogen %	Price.	Nitrogen %	Price.	Nitrogen %	Price.	Nitrogen %	Price.	Nitrogen %	Price.
1.—No Manure	1.66	48	1.63	45	1.54	40	1.39	77	1.47	67	1.21	77	1.52	55	1.59	65	1.55	45	1.91	37	2.26	37	1.39	60
2.—Complete Manure	1.58	53	1.71	43	1.59	40	1.45	70	1.53	70	1.19	77	1.62	52	1.69	70	1.70	45	2.11	37	2.13	37	1.52	60
3.—No Potash	1.60	53	1.70	43	1.51	40	1.65	68	1.61	67	1.18	77	1.56	52	1.56	70	1.73	45	2.17	37	2.14	37	1.52	60
4.—No Phosphate	1.66	53	1.75	43	1.60	40	1.53	71	1.52	67	1.18	77	1.58	52	1.47	77	1.66	45	2.06	37	2.12	37	1.48	60
5.—No Nitrogen	1.60	53	1.69	43	1.48	40	1.39	73	1.43	50	1.13	77	1.50	53	1.47	67	1.78	45	1.88	45	2.12	37	1.38	60
6.—Nitrogen Only	1.66	53	1.83	41	1.57	40	1.41	73	1.58	50	1.13	77	1.50	53	1.61	67	1.78	45	1.88	45	2.30	37	—	—
Average	1.62	52.9	1.70	42.7	1.55	40.0	1.49	71.2	1.52	65.2	1.18	75.0	1.58	55.0	1.55	68.7	1.65	45.0	2.01	37	2.28	37	1.38	50

TABLE I.

		Stiff Soils.		Medium Soils.		Light Soil.			Very Light Soil.	Chalk	
No.	Treatment.	Rothamsted.	Dunmow.	Eyton.	Wellington.	Porlock.	Harper Adams.	Chiselborough.	Sprowsdon.	Woburn.	Wye.
<i>Dressed Grain—Bushels per Acre.</i>											
1.	No Manure ..	(27.75)	32.35	30.00	36.42	23.73	34.36	23.0	(37.56)	16.60	47.4
2.	Complete Manure ..	(32.25)	31.00	54.18	46.25	23.55	42.21	27.0	(46.80)	21.15	47.7
3.	No Potash ..	(32.13)	44.91	54.00	46.92	24.84	38.00	24.0	(47.00)	22.90	46.4
4.	No Phosphate ..	(28.13)	37.21	46.50	43.00	20.13	31.79	35.0	(43.60)	24.65	48.2
5.	No Nitrogen ..	(26.00)	34.25	43.00	36.50	22.36	27.14	33.0	(42.20)	23.55	42.2
6.	Nitrogen only ..	(39.25)	39.50	48.82	41.00	21.45	40.50	35.0	(42.90)	20.70	—
<i>Total Grain Unmanured—100.</i>											
1.	No Manure ..	106	100	100	100	100	100	100	100	100	100
2.	Complete Manure ..	106	92	181	125	99	123	115	125	125	108
3.	No Potash ..	106	134	180	127	105	110	104	125	135	108
4.	No Phosphate ..	101	111	155	116	85½	93	149	116	145	104
5.	No Nitrogen ..	94	101	143	99	94	79	140	112	139	90
6.	Nitrogen only ..	141	118	150	111	90	120	148	114	123	—
<i>Dressed Grain Unmanured—100.</i>											
1.	No Manure ..	—	100	100	100	100	100	100	—	100	100
2.	Complete Manure ..	—	93	181	127	99	123	117	—	127	101
3.	No Potash ..	—	135	180	129	105	110	104	—	138	98
4.	No Phosphate ..	—	112	155	118	85	92	152	—	148	102
5.	No Nitrogen ..	—	103	143	100	94	79	143	—	142	89
6.	Nitrogen only ..	—	119	163	113	90	118	152	—	125	—

TABLE II.

Value per Acre of Dressed Grain to the Nearest Shilling.

Plot.	Rothamsted.	Dunmow.	Eyton.	Wellington.	Porlock.	Harper Adams.	Chiselborough.	Sprowsdon.	Woburn.	Wye.
1. No Manure ..	(166)	179	270	305	231	236	187	(211)	77	356
2. Complete Manure ..	(214)	167	475	405	229	290	236	(264)	98	358
3. No Potash ..	(212)	242	459	393	242	261	210	(264)	106	348
4. No Phosphate ..	(186)	200	413	360	196	218	306	(245)	114	361
5. No Nitrogen ..	(172)	184	392	319	218	186	289	(238)	109	316
6. Nitrogen only ..	(260)	202	446	356	209	278	293	(242)	95	—

APPENDIX I.

Centre.	Particulars of Soil, Field, and Plot Size.	Previous Cropping and Manuring	Date of sowing, 1925 Rate of Sowing.	Date of Applying Manure.	Season.
EASTERN SIDE.					
<i>Heils.</i> Rothamsted Experimental Station	Soil, clay with flints. Heavy strong soil, overlying chalk. Gt. Knott Field, 1/25 acre in duplicate.	Winter Oats Unmanured	March 26 1 bush per acre	March 25.	See Appendix II., and page 105
<i>Leid.</i> South-Eastern Agric. College.	Light calcareous loam. Field B. 1/5 acre in duplicate.	Roots 16 loads F A M 4 cwt Super, 4 cwt Kanit, 1 cwt Sulph Ammonia.	April 9 1 bush per acre	April 8	Wet April and May Dry June.
<i>Reds.</i> Woburn Experimental Farm Dr J. A. Voelcker	Thin light sandy loam Roadplace Field, 1/2 acre plot.	Swedes and Kohl rabi small crops, lightly fed off by sheep with little cotton cake. Dung 6 tons Super 3 cwt Sulph Pot 1 cwt Nit soda 1 cwt	March 11 1 bush per acre	March 31	The barley went in well. Drought from May 29-July 21.
<i>Ever.</i> Dunmow W. Hasler, Esq	Medina clay, Beefield Field, Barnston 1 acre plots	Mangolds for seed 1 cwt Peruvian guano, 1 cwt nitrate lime	April 20 2 1/2 bush per acre	April 14	Excellent growing weather till end of May, then drought. Harvest conditions poor.
<i>Suffolk</i> Orwell Park, Ipswich E. G. Petyman, Esq	Light sandy, White Posts Field, 2 of 4 acres, 2 of 1/2 acre	Turnips fed off by cows	April 20 2 bush per acre	April 29	May showers favourable to growing, drought later. Poor harvesting weather
<i>Norfolk</i> Suffolk Agric. Station, Sprowston, Norwich	Light gravelly loam. Field C 420 sq. yds. duplicate	Swedes and mangolds evenly distributed over all plots 10 tons F A M	March 11 3 bush per acre	April 1	Rainfall and temperature normal till early growth. Dry in June and July. Fair harvest weather.
<i>Lincolnshire</i> Wellington G. H. Neville, Esq	Oolitic limestone Lincoln Heath light loam, about 8 in of soil High Dyke Field.	Malting barley plot with standard manuring	March 11 & 14 1 1/2 bush per acre	March 28	Sufficient rain for germination, warm weather favoured tillering. Four weeks of abnormal drought from May 27-Aug 5. Good harvesting.
<i>Yorkshire</i> Gresley	Strong loam overlying chalky soil Top Burton Field, 4 acre plots	Turnips eaten on	April 15 & 18 1 bush per acre	April 10 & 14	Land rather moist Good growing weather.
WESTERN SIDE					
<i>Shropshire</i> Hagger Adam College, Newport	Medium loam Field C, College Farm 1 acre in duplicate	Globe turnips. Carted off 2 cwt Super 1 cwt Muriate of Potash.	May 20 1/2 bush per acre	May 6	Rain delayed seeding and soil was rather moist. 8 weeks of drought immediately followed. Mid-July to harvest favourable weather.
<i>Wiltshire</i> Craig Tanner Esq.	Red medium gravelly loam Marsh Field; 1 acre plots.	Turnips. 1/2 ton slag per acre.	March 21, 2 1/2 bush per acre	April 1	Wet growing weather in April & May followed by drought. Rain again before harvest.
<i>Somerset</i> Stoke under Ham Chiselborough Messrs. R. A. Clarke & Sons	Inferior boulder light sandy soil Plain Gowers field 1 acre plots.	Seeds hay, fed off.	April 18 1 bush per acre	April 13	Late starting season, with abnormal rain till June. Then dry till mid-July Fair harvest weather.
<i>Wiltshire</i> T. H. Rawle, Esq	Stonebrash derived from Red Sandstone, Ten acre Field. 1/2 acre plots.	Cattle cabbage, fed off.	March 20, 2 1/2 bush per acre	March 20	April and May very wet. Hot dry June, which improved appearance of barley Good rain before harvest and good conditions for cutting.

APPENDIX II.

ROTHAMSTED RAINFALL.		June ..	July ..	August ..	September ..	0099
Oct. 1924-Dec. 1924 ..	.. ..	10.646	.. ..	.. ..	.. ..	4.241
Jan.-Feb. 1925 ..	.. ..	5.672	.. ..	.. ..	.. ..	2.862
March ..	.. ..	1.149	.. ..	.. ..	.. ..	3.083
April ..	.. ..	1.599	.. ..	.. ..	.. ..	.. ..
May ..	.. ..	2.351	.. ..	.. ..	.. ..	.. ..
		Total	.. ..	.. ..	.. ..	31.702

THE INSTITUTE OF BREWING RESEARCH SCHEME.

FIFTH REPORT ON THE INFLUENCE OF SOIL, SEASON AND MANURING ON THE QUALITY AND GROWTH OF BARLEY, 1926.

By SIR E. J. RUSSELL, O.B.E., D.Sc., F.R.S (DIRECTOR, ROTHAMSTED EXPERIMENTAL STATION, HARPENDEN, HERTS.).

THE first series of experiments had closed in 1925 and showed clearly that except in a few districts, neither phosphates nor potassic fertilisers added appreciably to the yields of barley under the conditions of a good barley growing farm, nor did they improve the valuation. Potassic fertilisers tended to lower the nitrogen content of the grain, but not sufficiently to alter the appearance of the grain, consequently the Valuation Committee were not prepared to award a higher price. Only at the Norfolk centres had superphosphate given an increase in crop, but even there not much.

Sulphate of ammonia, on the other hand, and still more, as far as the experiments went, muriate of ammonia, gave an increased yield of 5 or 6 bushels per acre for 1 cwt. of the fertiliser, costing about 11s. therefore a distinctly profitable increase for the farmer. The appearance of the grain was not usually affected, and the Valuation Committee in general assessed these samples at the same value as those grown without nitrogen. The percentage of nitrogen in the grain was sometimes lowered and sometimes raised, but only by a small amount in any case. All the samples of barley obtained in the experiments were fully analysed as also were the malts obtained by the stock-ing method. These also were not appreciably affected. It was not possible at any time during this set of experiments to get a large scale malting done.

Fortunately for the Institute, Mr. H. D. Cherry-Downes came forward and undertook to arrange for large scale maltings to be done in 1926, at Messrs. Gilstrap, Earp & Co. Maltings, at Newark. This enabled the Committee to carry out a new series of experiments, the purposes of which were:—

(1) To test on the large scale the conclusion that nitrogenous manuring at the above mentioned rate does not lower the value of the barley or the malt.

(2) To correlate the analytical data with each other and with the maltsters reports and data, and to discover as far as possible the interpretation to be put upon the analytical data.

These large scale maltings entail much work, and the Institute owes a great deal of gratitude to Mr. Cherry-Downes and to Messrs. Gilstrap, Earp & Co, also to Mr. J. S. Ford, and Messrs. William Younger & Co., Ltd., who malted the Dunbar barley, for their generous assistance and co-operation.

The field plots were so arranged as to provide 30 quarter samples. There were only two treatments except at Fakenham where muriate of ammonia was also used. These were, no manure, and sulphate of ammonia 1 cwt. per acre, but there were two plots of each treatment, making four plots of two acres each. At Chiscliborough there were 6 plots. Arrangements were made for bulk experiments at 12 centres. These were Dunbar, Dunmow, Cawkwell, Wellingore, Chiscliborough, Fakenham, Sprowston, Beverley, Longniddry, Nynhead, Rothamsted, Wye. At two of these the weights are not available, but the samples were fully examined. Except at Cawkwell, where Mr. Davy used his own supply of Spratt-Archer, the barley grown at each centre was, as before, a uniform stock of Beaven's Plumage-Archer (1924) supplied by Messrs. Hasler, of Dunmow. Small plots with 6 different treatments were laid down at four centres in continuation of the experiments of former years, at Rothamsted and Sprowston, in addition to bulk plots, and at Woburn and Newport small plots only. At one of these, the Harper Adams College, Newport, the plots were so badly laid that harvesting was very difficult, and had to be done with a scythe. At Rothamsted and Woburn there were additional plots with muriate of ammonia. The results are given in Tables 1 and 3.

MALTING BARLEY, 1926.

TABLE 1.—Continuation of Series I.

ROTHAMSTED. SUMMARY OF RESULTS.* (NEW ZEALAND FIELD.)

Average Yield per Acre.	Super + S/Amm. + S/Pot.	Super + S/Amm.	S/Amm. + S/Pot.	Super + S/Pot.	S/Amm.	Super + S/Pot. + M/Amm.	Super + M/Pot. + S/Amm.	Control.	General Mean.	Stand- ard Error.
Grain, pounds ..	2306	2352	2313	2493	2213	2480	2384	2235	2346.7	105.25
Straw, pounds ..	4172	4525	4419	4172	4228	4475	4547	3916	4306.6	108.73
Grain, bushels ..	44.35	45.22	44.49	47.04	42.56	47.69	45.84	42.98	45.13	2.02
Straw, cwt. ..	37.25	40.40	39.45	37.25	37.75	39.96	40.60	34.96	38.45	0.97
Grain, per cent. ..	98.27	100.20	98.57	106.22	94.30	105.65	101.57	95.24	100	4.48
Straw, per cent. ..	96.87	105.07	102.60	96.87	98.18	103.91	105.58	90.92	100	2.52
Total produce, pounds	6478	6877	6732	6665	6441	6955	6930	6151	6653.4	—

* For fuller information, see Rothamsted Report, 1925-6, p. 149. For analysis see p. 328.

WOBURN.

Plot.	Manures per Acre.	Head Corn.				Tail Corn.				Straw, Chaff, etc.
		Bushels.	Weight per Bushel.							
1.	Nothing ..	32.2	lb. 53.7		lb. 114	T.	cwt.	qr.	lb.	
2.	Super, 3 cwt.; S/Potash, 1½ cwt.; S/Am- monia, 1 cwt. ..	48.5	52.7		252	1	16	3	8	
3.	Super, 3 cwt.; S/Ammonia, 1 cwt. ..	41.6	52.7		126	1	9	0	22	
4.	S/Potash, 1½ cwt.; S/Ammonia, 1 cwt. ..	42.9	52.3		175	1	16	0	27	
5.	Super, 3 cwt.; S/Potash, 1½ cwt. ..	35.3	53.4		147	1	4	2	8	
6.	S/Ammonia, 1 cwt. ..	39.3	52.1		160	1	13	3	20	
7.	Muriate of Ammonia = 1 cwt. S/Ammonia ..	47.1	52.9		148	1	13	3	13	
8.	Super, 3 cwt.; S/Potash, 1½ cwt.; Muriate of Ammonia = 1 cwt. S/Ammonia ..	41.1	53.1		167	1	10	3	13	

The season was unfavourable to high yields of good quality. The winter had been hard and spring was late; there were droughts in March and early April, which interfered with germination, and then much rain; a cold May injured the plant, then came drier and warmer weather in the latter part of June and first part of July, when the crop improved considerably and held out great promise; then in the second half of July heavy rains and gusts of wind severely laid many of the crops—indeed laid cereal crops were a feature of the season. August was drier and favourable for harvest: had the corn not been laid it would have been reaped in record time. Unfortunately, the lodging caused so much delay that barley

was still standing out in September, when it was heavily rained upon and began to sprout in the moist warm period that followed. In these circumstances the yields were not high, and wherever the barley was badly laid by the storms there were serious losses. Only at Wye, Rothamsted and Longniddry did the yields exceed 40 bushels per acre.

The season differed from its predecessors in our experimental series by its sunlessness. Others have been wetter—notably 1924—but none at Rothamsted has been so devoid of sunshine. The deficiency is especially marked in the important months of May, June and July; the number of hours of sunshine at Rothamsted were:—

TABLE 2.—*Sunshine Record.*

	1922	1923	1924	1925	1926
May ..	280.2	166.2	190.9	204.7	153.6
June ..	228.8	116.1	199.6	259.5	180.7
July ..	149.5	223.8	236.1	183.6	151.1
Total ..	658.5	506.1	526.6	647.8	485.8

The effect of the nitrogenous manure also differed from that of previous years. In all the years 1922 to 1925 inclusive, 1 cwt. sulphate of ammonia has increased the yield of barley by some 5 or 6 bushels per acre. In 1926 this increase was obtained only at six centres out of the eleven for which weights are available—at Woburn, Sprowston, Cawkwell, Wellingore, Nynhead, and Chiselborough; at the other five there is no increase; indeed at Rothamsted, Long-

niddry and Wye there is definite evidence of a decrease; at Dunmow and Beverley the yields of the duplicate plots are not near enough to show whether there has been a decrease or not. The result is of special interest as suggesting that the ineffectiveness of the nitrogenous manure may be the result of the wet sunless conditions; indeed that in these conditions nitrogenous manures may have a harmful effect which does not appear in warmer weather. This is somewhat unexpected, but it is supported by the results of the other series of experiments which is being continued at Rothamsted and Woburn though discontinued elsewhere. At Rothamsted it is on an elaborate plan allowing of calculation of the standard error. In a sunless season potassic fertilisers are expected to act well; this happened at Roth-

MALTING BARLEY. *2nd Series.* 1926.

TABLE 3.—*Yields of Barley, Bushels (56 lb. weight) per Acre, 1926.*

	Head Corn.			Seconds.		
	1 cwt. Sul' Amm. per acre.	No Manure.	Gain from Sul/Amm	1 cwt. Sul Amm. per acre.	No Manure.	Gain from Sul/Amm.
<i>Eastern Districts.</i>						
Rothamsted	(a) 42.56	42.98	— 0.42	—	—	—
	(b) 44.35	47.94	— 3.6	—	—	—
Woburn	(a) 39.3	32.2	7.1	—	—	—
	(b) 28.5	35.3	13.2	—	—	—
Wye	48.3	50.52	— 2.2	9.1	6.1	+ 3.0
Dunmow	21.75	22.75	— 1.00	5.63	9.0	— 3.37
Sprowston (Norwich)	49.5	38.5	+ 11.0	—	—	—
Wellingore	27.05	21.95	+ 5.10	4.69	4.24	+ 0.45
Cawkwell	30.50	27.63	+ 2.87	8.00	4.84	+ 3.16
Beverley	32.9	32.1	+ 0.8	—	—	—
Longniddry	44.38	48.50	— 4.12	—	—	—
<i>Western Districts.</i>						
<i>Somerset.</i>						
Chiselborough	38.97	33.50	+ 5.47	0.91	1.00	— 0.09
Nynhead	36.29	31.43	+ 4.86	1.06	1.00	+ 0.06

(a) No other manure.

(b) Superphosphate and sulphate of potash in addition.

amsted; the yield of barley, in bushels per acre, was:—

TABLE 4.

	No Nitrogen	Sulphate of Ammonia	Sulphate of Ammonia and Super.
No Potash ..	42.98	42.56	45.22
Potassium Sulphate	47.94*	44.49	44.35
Gain ..	5	2	—0.87

* and Superphosphate.

The other data on the same line make it unlikely that the superphosphate contributed in an important way to the result. But as soon as nitrogen is added the good effect of the potash is in part counteracted and its advantage is lost.* The harmful action of

* This difference in behaviour between potassic and nitrogenous fertilisers is probably attributable to the fact that potassium increases the efficiency of the leaf as an assimilating organ, while nitrogen increases only its area. In the sunless season the increased efficiency is apparently worth more than the increased area.

TABLE 5.—Composition of Barley Grain. Series II.

	Moisture.		Nitrogen.		Valuation in Shillings per Qr		1,000 Corn weight.		Malting Loss.	
	No. Manure	Sul. of Amm.	No. Manure	Sul. Amm.	No Manure	Sul. of Amm	No. Manure.	Sul. Amm.	No. Manure.	Sul. Amm
Rothmasted ..	18.5	18.7	1.577	1.662	39	38	40.1	38.1	7.3	7.0
Woburn ..	16.2	16.7	1.522	1.610	46	39	36.2	34.1	8.7	8.9
Wye ..	16.8	17.3	1.576	1.569	46	44	40.4	38.4	10.5	9.9
Dunmow ..	17.3	17.1	1.535	1.507	43	45	36.9	37.4	8.5	9.1
Sprowston ..	18.4	18.3	1.447	1.623	40	38	33.6	34.0	7.6	7.8
Fakenham ..	18.5	18.3	1.466	1.492	44	40	33.4	32.7	8.3	8.4
Wellingore ..	17.6	16.2	1.396	1.370	42	45	31.2	33.0	10.0	10.3
Cawkwell ..	16.6	17.0	1.663	1.714	39	39	30.5	30.8	10.1	9.3
Beverley ..	16.8	16.7	1.496	1.572	37	37	35.7	32.7	10.6	9.7
Dunbar ..	16.9	16.7	1.516	1.536	46	46	39.7	40.9	7.5	7.7
Longniddry ..	16.9	16.8	1.380	1.424	47	44	38.2	36.9	7.5	7.3
Chiselborough ..	17.1	17.1	1.435	1.487	56	49	37.0	34.4	7.9	7.5
Nynehead ..	17.4	16.6	1.440	1.393	51	48	43.3	37.6	7.4	8.7

Series I.—1926.

	Moisture, per cent.		Nitrogen per cent. in dry matter.		1,000 corn weight (dry).		Malting Loss.	
	Rothamsted.	Woburn.	Rothamsted.	Woburn.	Rothamsted.	Woburn.	Rothamsted.	Woburn.
No Manure ..	17.0	16.2	1.604	1.522	38.4	36.2	9.8	8.7
Complete Artificial	17.0	15.9	1.711	1.598	38.8	35.6	9.9	10.2
No Potash ..	16.9	16.1	1.673	1.545	37.3	33.7	9.6	10.0
No Phosphate ..	17.5	16.3	1.710	1.625	37.1	35.3	9.0	9.7
No Nitrogen ..	17.0	15.7	1.599	1.513	38.4	37.6	9.8	9.6
Sulphate of Ammonia only ..	17.0	16.7	1.685	1.610	36.9	34.1	9.8	8.9
Muriate of Ammonia only ..	—	16.1	—	1.449	—	35.8	—	9.6
<i>Complete Artificial.</i>								
All Sulphates ..	17.0	15.9	1.711	1.598	38.8	35.6	9.9	10.2
Muriate of Ammonia ..	17.2	16.3	1.684	1.491	36.8	36.6	9.3	8.6
Muriate of Potash ..	17.4	—	1.726	—	36.4	—	9.3	—

nitrogenous manure in this sunless season is shown also in the effect on the grain. In preceding years this effect has been small. In 1926 it is more distinct. At seven centres out of the twelve the sulphate of ammonia raised the percentage of nitrogen; these were Longniddry, Fakenham, Cawkwell, Chiselborough, Sprowston, Beverley, and Rothamsted; at the last three the increase amounted to more than 0·05 per cent : only at Nynehead, Dunmow, Wellingore, was the percentage lowered, while at Wye and Dunbar it was unaffected. Also the 1,000 corn weight was reduced by nitrogenous manuring at seven centres, viz., Longniddry, Fakenham, Chiselborough, Beverley, Rothamsted, Nynehead and Wye, while it was increased at Dunbar, Dunmow, Wellingore, and unaffected at Cawkwell and Sprowston. This adverse effect of nitrogenous manure showed itself also in the valuations, the

brought it down. Thus the Chiselborough unmanured barley was valued at 56s. while that receiving sulphate of ammonia was put at 49s. only, a drop of 7s. per quarter, which almost entirely wiped out the profit from the extra 5·5 bushels per acre given by the fertiliser. Similarly the Nynehead and Longniddry barleys grown with nitrogenous fertiliser were valued below those grown without it. The difference persisted into the malts, where, indeed, it became more pronounced. The analytical data throw but little light on the decreased valuations; the 1,000 corn weight is in all three cases lowered by the nitrogenous manure, which might account for some part of the decreased valuation, but the valuations at the different centres do not correspond with the respective nitrogen percentages.

The data are :—

TABLE 6

Place.	Barley.						Malt.	
	Valuation Shillings per quarter.		Nitrogen* per cent.		1,000 Corn* Weight.		Valuation.	
	No Manure	Nitrogen- ous Manure	No Manure.	Nitrogen- ous Manure	No Manure	Nitrogen- ous Manure	No Manure.	Nitrogen- ous Manure.
Chiselborough ..	56	49	1·435	1·487	37·0	34·4	82	73
Nynehead ..	51	48	1·440	1·393	43·3	37·6	81	62
Longniddry ..	47	44	1·380	1·424	38·2	36·9	71	58

*On barley dried in current of dry air at 98°C

first time this has happened in all the five years of the experiments. Where the barley already commanded only a low price, the nitrogenous manure made no consistent difference (Table 5), but where the valuation was high, nitrogenous manuring

Lodging affords some explanation; its influence on valuation at Longniddry is very marked, but here it goes with increased nitrogen content and decreased 1,000 corn weight. The barley that was the worst lodged had the highest nitrogen content, and

TABLE 7.

State of Lodging.	Valuation	Yield, Bushels per acre.	Treatment.	Nitrogen per cent.	1,000 Corn weight.
No. 2. Badly ..	42/-	43	Sulphate of ammonia	1·466	35·6
No. 1. Half ..	42/-	51	No Nitrogen	1·395	37·5
No. 4. Half ..	44/-	46	Sulphate of ammonia	1·383	38·3
No. 3. Stood up ..	46/-	46	No nitrogen	1·366	38·9

the lowest 1,000 corn weight, that on the other plots varying in the same order as the state of lodging.

INFLUENCE OF NITROGENOUS MANURING ON VALUATION OF THE MALTS.

I.—*The Stocking Malts.*

The results are set out in Table 8.

Nitrogenous manuring has lowered the valuation of practically all the malts priced 60s. or more, but it has not affected the valuation of the malts of lower price. The diastatic power, however, tends to increase where nitrogenous manure is given wherever the percentage of nitrogen in the grain is also increased; this is seen at Beverley, Fakenham, Rothamsted, and Sprowston, Longniddry and Chiselborough; the diastatic power is not increased, however, at Dunmow, Nynhead, Wellingore, Dunbar and Cawkwell; all, except Cawkwell, centres where the nitrogen content of the grain was not increased by the manuring.

The results show considerable agreement with those of the stocking malting. The valuations of the malts from different centres come out in the same order by both methods; for the unmanured samples Chiselborough comes out first, followed by Dunbar and Longniddry, which are practically equal. There is some disagreement at the bottom of the scale, but nothing of importance. (Table 9).

The bulk and stocking methods, however, show some disagreement as between the manured and unmanured barleys at the same centre. Malts obtained in bulk from barleys receiving nitrogenous manure were not, as a rule, valued lower than those grown without manure; only for the Longniddry and Sprowston samples is there any marked reduction of valuation, and against this is Dunbar, where there is a marked increase in valuation; for the other centres the difference is only a shilling or so, and it is

TABLE 8.

Effect of Nitrogenous Manuring on Composition and Valuation of Malt (Stocking Method).

	Extract.		Colour.		Diastatic Power.		Cold Water Extract.		Valuation.	
	No Manure	Nitrogenous Manure.	No Manure.	Nitrogenous Manure.	No Manure	Nitrogenous Manure.	No Manure.	Nitrogenous Manure.	No Manure	Nitrogenous Manure.
Chiselborough ..	100.6	100.1	3.2	3.2	46.0	49.7	19.2	19.6	82	73
Nynhead ..	99.1	99.7	3.2	3.5	48.5	49.0	19.5	21.5	80	62
Longniddry ..	101.2	99.9	3.0	3.3	50.0	58.0	19.4	20.1	71	58D
Dunbar ..	100.1	100.2	4.0	4.0	43.5	42.7	20.1	19.2	71	72
Dunmow ..	100.0	99.9	4.0	4.4	52.0	48.0	21.7	22.1	63	61
Fakenham ..	99.4	98.6	3.5	3.7	34.2	37.4	19.4	20.2	63	62
Sprowston ..	99.7	99.0	3.3	4.0	50.5	55.5	20.2	21.7	60	58
Wye ..	99.1	97.4	5.9	5.3	46.2	55.2	22.6	22.5	58	55
Rothamsted ..	99.0	99.1	4.5	4.3	54.5	57.0	20.1	20.5	57	58D
Wellingore ..	98.3	98.7	5.2	5.5	40.4	42.6	23.3	23.5	56	58
Cawkwell ..	97.7	98.1	5.0	4.5	48.9	47.9	23.1	22.0	56	54
Beverley ..	98.4	97.1	5.4	4.8	54.2	59.2	23.4	22.3	52	52

It is interesting that the centres where manuring with sulphate of ammonia lowered the valuation of the barley were also usually those where it lowered the valuation of the malt.

II.—*The Bulk Malts.*

Nine of the experimental lots were malted in bulk by Gilstrap, Earp & Co. Ltd., and William Younger & Co. Ltd.

sometimes one way and sometimes the other.

Except at Rothamsted, the diastatic power of the malts from manured barley is everywhere greater than from the unmanured, even at Dunbar and Dunmow, where the nitrogen content of the grain had not been increased by the manure.

The other properties, colour and extract were not affected to any significant extent by the manuring.

TABLE 9.
VALUATION OF BULK AND STOCKING MALTS.
Unmanured Barley.

Bulk.			Valuation of Malt. Shillings per qr.	Stocking.	Valuation of Malt.* Shillings per qr.
Chiselborough	..	..	83	Chiselborough	.. .. 82
Dunbar	..	..	80	Dunbar	.. .. 71
Longniddry	..	..	75D	Longniddry	.. .. 71
Dunmow	..	..	70	Dunmow	.. .. 63
Sprowston	..	..	70	Sprowston	.. .. 60
Wellingore	..	..	66	Rothamsted	.. .. 57
Beverley	..	..	62	Wellingore	.. .. 56
Rothamsted	..	..	57	Cawkwell	.. .. 56
Cawkwell	..	..	57	Beverley	.. .. 52

Barleys Manured With Sulphate of Ammonia.

Bulk.			Valuation of Malt. Shillings per qr.	Stocking.	Valuation of Malt. Shillings per qr.
Dunbar	..	..	85	Chiselborough	.. .. 73
Chiselborough	..	..	80	Dunbar	.. .. 72
Dunmow	..	..	69	Dunmow	.. .. 61
Wellingore	..	..	67	Wellingore	.. .. 58
Longniddry	..	..	66	Longniddry	.. .. 58D
Rothamsted	..	..	62	Rothamsted	.. .. 58
Beverley	..	..	60	Sprowston	.. .. 58
Sprowston	..	..	58	Cawkwell	.. .. 54
Cawkwell	..	..	58	Beverley	.. .. 52

*The level of values for the bulk malts is higher than that for the stocking malts, because the latter had not been dressed

EFFECT OF SOIL AND SEASON ON NITROGEN CONTENT AND 1,000 CORN WEIGHT OF GRAIN.

Nitrogen and Corn Weight.—The data for these are given in Table 3. The nitrogen content of the grain is of the same order as

in previous years, but usually slightly less, and as usual it is more influenced by the farm (presumably by the soil) than by season. It has been, on the unmanured plots, at the centres arranged in order of heaviness of soil :—

TABLE 10.—*Per Cent. of Nitrogen in Grain of Unmanured Barley.*

	1922.	1923.	1924.	1925.	1926.	Varies round
Rothamsted	.. .. 1.60	1.71	1.62	1.66	1.58	1.6
Cawkwell	.. .. 1.56	1.40	1.27	—	1.66*	—
Beverley	.. .. —	1.29	—	1.54	1.50	1.5
Wellingore	.. .. 1.76	1.49	1.42	1.47	1.40	1.45
Chiselborough	.. .. —	1.49	1.46	1.59	1.43	1.45
Wye	.. .. —	—	1.74	1.39	1.57	—
Barneyhill	.. .. 1.36	1.59	—	—	1.52	—
Dunmow	.. .. 1.75	2.23†	1.56	1.63	1.53	1.6
Woburn	.. .. 1.78	1.92	1.23	1.91	1.52	—
Orwell Park	.. .. 1.43	1.98	1.59	2.26	—	—
Newton St. Faith	.. .. —	—	1.33	—	—	—
Sprowston	.. .. —	—	—	1.55	1.51	—
Porlock	.. .. —	—	1.30	1.21	—	—

* Spratt Archer, not Plumage Archer, like all the rest.

† Not the same Plumage Archer as the rest.

In spite of the very marked differences in the season the percentage of nitrogen in the unmanured plots has altered but little during all the five years at Rothamsted; it runs round about 1·6, though the yields have varied from 21·4 to 43 bushels. At Wellingore for the last four years it ran about 1·45; the yields varying over the same years from 21·9 to 43·3; only in the first year was the value much different. At Chiselborough, out of four years, three are close to 1·45, only the fourth was out of step. At Dunmow the 1923 value is out of line, but in that year a different strain of seed was used. At Woburn and at Orwell Park the values range round two different figures: this is being further studied. What exactly is the farm factor we do not know; the problem will be discussed in the complete summary of the experiments.

The weight per 1,000 corns is less than in previous years; it shows somewhat less variation from season to season on the same farm than does the percentage of nitrogen.

TABLE 11.
The 1,000 Corn Weight * Unmanured Barley.

Unmanured Plots	1922	1923	1924	1925	1926
Rothamsted	39·5	41·0	40·6	39·4	40·1
Cawkwell ..	36·8	42·5	36·9		30·5
Beverley ..		38·5		37·9	35·7
Wellingore ..	40·7	40·4	39·2	37·5	31·2
Chiselborough		40·3	36·4	41·5	35·9
Wye ..			40·5	42·3	40·4
Barneyhill ..	46·6	39·2			39·7
Dunmow ..	38·6		39·1	41·2	36·9

*On dry barley.

THE EFFECT OF MURIATE OF AMMONIA.

Muriate of ammonia having given better results than sulphate of ammonia in the tests made at Rothamsted during the preceding years, it was in 1926 tested at three

of the centres, Rothamsted, Fakenham, and Woburn. At each of these centres the muriate again came out better than the sulphate. At Rothamsted it caused none of the depression of yield shown by the sulphate. The figures are:—

	Bushels per acre.
Muriate of Ammonia	47·69
Sulphate of Ammonia	44·35
No Nitrogen	47·94

Superphosphate and sulphate of potash given to all three plots.

While, therefore, in this exceptional season the muriate gave no gain in crop, it was free from the risk of injury shown by the sulphate.

At Woburn the muriate gave a satisfactory increase.

At Fakenham, although no yields are available, the muriate gave greater satisfaction to the grower since it brought the barley into ear rather sooner than the sulphate and so made possible a longer ripening period. It also brought about a lowering of the percentage of nitrogen in the grain at Woburn below that of the barley grown with sulphate of ammonia or without any nitrogen, as in preceding years: but not, however, at Fakenham. It raised the 1,000 corn weight and the valuation of the barley in comparison with sulphate of ammonia at Fakenham and Woburn: at Rothamsted, however, the 1,000 corn weight was somewhat less and the valuation, already low, was not altered. Fakenham was the only centre that gave a good malt, and here the muriate gave by far the best results.

Taken altogether, the results agree with those of previous years in showing a superior value for muriate of ammonia over sulphate of ammonia. The effect is in some way specific to muriate of ammonia; it is not shown by muriate of potash.

TABLE 12.

	Percentage of Nitrogen in Grain.					Valuation.				
	Rothamsted.		Woburn.		Fakenham.	Barley.		Malt.		
	(a)	(b)	(a)	(b)		(a)	(b)	(a)	(b)	
No Nitrogen	1·599	1·513	1·522	1·466	41	46	46	44	53	65
Sulphate of Ammonia ..	1·711	1·598	1·610	1·492	39	40	39	40	54	52
Muriate of Ammonia ..	1·684	1·491	1·469	1·562	30	41	45	42	51	62

(a) Phosphate and potash in addition (Series I). (b) No other manure.

SUMMARY.

The season of 1926 differed completely from those of the earlier experiments, 1922 onwards, in having far less sunshine during the growing season of the barley. This brought out two important properties of the nitrogenous manuring that had not been observed in any of the previous experiments.

(1) The nitrogenous manure in nearly half the experiments gave no increase in crop; indeed there was some evidence at Rothamsted and elsewhere of a harmful effect on yield.

(2) It tended to lower the valuation of the barley and of the malt, especially those of higher price and to raise the percentage of nitrogen in the barley and lower the 1,000 corn weight. If 1926 were typical it would be necessary to revise the conclusions of the last four reports: it was, however, distinctly abnormal.

During this season large scale maltings were made as well as stocking maltings. The valuations of the malts from different centres for the unmanured barleys and for the manured barleys respectively came out in substantially the same order by both methods: the only discrepancies are at the lower end of the scale, where differences are not particularly important. As between the manured and unmanured barleys at the same centre, the two methods show some disagreement.

At one centre it was possible to study the effect of "lodging" of the barley on the valuation of the grain and the properties of

the malt. The worst lodged barley had the lowest valuation, the highest nitrogen content, the lowest 1,000 corn weight. The least lodged had the highest valuation, lowest nitrogen content and highest 1,000 corn weight, while those lodged to an intermediate degree came intermediate in these various properties. (Table 7.)

The diastatic power of the malts was higher where the barley had received sulphate of ammonia than where it had not. There are indications that diastatic power is increased when the nitrogen of the grain increases.

In spite of the abnormal character of the season the percentage of nitrogen in the barley grain did not differ to any important extent from those of the previous years. Reviewing the results obtained up to the present it appears that nitrogen percentage in the grain is affected more by the farm (presumably the soil) than by the season, or the manuring, provided this is not too heavy. It is difficult to know what the soil factor may be. The 1,000 corn weight is slightly less variable.

As before, muriate of ammonia proved rather better than sulphate of ammonia. It showed none of the harmful effect of the sulphate at Rothamsted, and at Rothamsted and Woburn it lowered the percentage of nitrogen in the grain as compared with sulphate of ammonia. It does not appear that muriate of potash has the same effect. In the 1927 experiments this question is tested more fully.

APPENDIX TO BARLEY REPORT.

LIST OF FARMERS CARRYING OUT EXPERIMENTS IN 1926.

G. H. Neville, Wellingore Hall, Lincs.

Norfolk Agricultural Station, Sprowston, Norwich.

J. H. Spilman, Gardham, Etton, Beverley, Yorks.

R. A. Clarke & Sons, Manor Farm, Chiselborough, Somerset.

South Eastern Agricultural College, Wye, Kent.

Rothamsted Experimental Station, Harpenden, Herts.

L. Mortimer, Haywood Farm, Nyncehead, Somerset.

Sir Harry Hope, Barneyhill, Dunbar.

W. Bruce & Sons, Seton Mains, Longniddry, East Lothian.

Wm. Hasler, Dunmow, Essex.

T. J. Young, Harper Adams Agricultural College, Newport, Salop.

Dr. J. A. Voelcker, Woburn Experimental Farm, Aspley Guise, Beds.

A. E. Davy, Cawkwell, Louth, Lincs.

H. V. Sheringham, South Creak, Fakenham, Norfolk.

Observations on the Plots: Season 1926.

Dunmow.—Phillpott's Field, heavy soil.

Owing to the heavy storms, the field was badly laid in places, which adversely affected both the yield and quality.

Four plots, each of four acres. Previous crop, mangolds, Kohl rabi, and swedes, which, however, ran across the barley plots, so that the conditions applied equally to all. Barley sown, March 22nd; manure applied at same time, rate of seeding, $2\frac{1}{2}$ bushels per acre, seeded rough. Long dry spell after sowing caused barley to come up irregularly. Sulphate of ammonia showed no effect till early in June when the manured plots stood out as darker in colour, and early began to look the best. The roots had received 15 loads of dung per acre.

At the north end, where mangolds had followed lucerne and then failed, the barley was distinctly better than the south end, but, later in the season, the barley was so badly laid that the plots could not be separated. This part was therefore taken out, thus reducing the plots to three-and-a-

Yields per Plot (4 Acres) as Returned.

<i>Yield per Acre (2 Acres) as Returned.</i>														
No Manure.						Sulphate of Ammonia.								
Head Corn.			Tail Corn.			Head Corn.			Tail Corn.					
	qr.	bu.	lb.	qr.	bu.	lb.		qr.	bu.	lb.		qr.	bu.	lb.
No. 1 ...	9	2	20	3	3	19	No. 2 ...	9	7	22	2	1	48	
No. 3 ...	10	3	26	2	4	25	No. 4 ...	11	6	34	3	2	52	

half acres. The plots were weedy, there being much thistle and charlock.

Longniddry.—Plots four acres. Previous crop, oats. The whole field had light dressing of superphosphate and potash salts. Seed-bed excellent. Plots (1) and (2) were laid, plots (3) and (4) stood up better; they were on the heavier and poorer side of the field. The crops lodged and ripened too quickly. The yields are $2\frac{1}{2}$

bushels less than expected in a good year, and the sample is thin and lean looking.

Wellingore. High Dyke Field.

1925 crop red clover hay. Second out left for seed. No manure. 1924 crop barley, which received 3 cwt. superphosphate, 2 cwt. kainit, and 1 cwt. sulphate of ammonia, yield $42\frac{1}{2}$ bushels. Rate of drilling, 12 pecks (=3 bushels). March 4th and 5th. Manures

Yields per plot (4 acres) as returned.

No Manure.					Sulphate of Ammonia.				
Head corn.				Tail corn.	Head corn.				Tail corn.
No. 1	tons.	cwt.	lb.		No. 2	tons.	cwt.	lb.	
...	5	2	0	Not	...	4	5	42	
No. 3	...	4	12	-	No. 4	...	4	12	56
				stated.					stated.

harrowed in March 26th. Crop harvested August 26th. Little rain from February 20th to April 5th, afterwards well distributed rainfall throughout the growing season, but little sun or drying wind. This caused more straw than usual. The crop was cut August 26th, but while it was still in stock in September, there came heavy rain, which, com-

bined with the muggy conditions, caused weathering and loss of brightness, considerably depreciating the value of the crop. The average yield was just under 25 bushels, as against 43 for the two earlier seasons. Rainfall in mm. during the growing season for the four years of the experiments at Wellington :—

				Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
Mean ...	...	...	...	45	40	42	38	50	50	60	66	42
1923 ...	...	...	...	—	88	41	20	59	20	96	48	—
1924 ...	...	...	...	45	17	13	33	67	48	52	60	54
1925 ...	...	...	...	38	48	24	32	74	3	23	35	79
1926 ...	...	...	...	58	27	13	46	71	61	40	60	20

Yields per acre, as returned.

No Manure.			Sulphate of Ammonia.		
Head corn.		Tail corn.	Head corn.		Tail corn.
bushels.		bushels.	bushels.		bushels.
No. 1 ...	23.3	3.63	2	25.6	4.84
No. 3 ...	20.6	4.84	4	28.5	4.54

Nynehead. Big Field, red light soil, good for barley.

Previous crop young grass, folded by sheep. Sown March 8th, 12 pecks per acre; seed went in well. Manures applied March 8th, drought after sowing, so the crop came up irregularly. Plot 4 (Sulphate of Ammonia)

much the best in June, though not in final yield. Plot 2 (duplicate Sulphate of Ammonia) not so good.

Early in April wireworms had been busy on the plot. The land, however, was rolled three times and a plant was secured all over the field, though thin in places.

Yields per plot, as returned.
(3.5 acres, Plot 4, 3.3.)

No Manure.			Sulphate of Ammonia		
Head corn.		Tail corn.	Head corn.		Tail corn.
Sacks.		Sacks.	Sacks.		Sacks.
No. 1 ...	26	2	No. 2 ...	32	5
No. 3 ...	29	4	No. 4 ...	30	4

Barneyhill. Sandyknowe. Good red soil, inclined to be dry.

Previous crop, potatoes, receiving farmyard manure and 11 cwt. per acre potato manure. Sown March 24th, 2½ bushels per acre. Seed went in well. Manures applied March 24th. Very wet weather April and first half of May.

Cawkwell. The Helens Field, light loam, chalk.

Previous crop and manures, farmyard manure applied in November on grazed seed; four acre plots. The seed went in well; plots receiving ammonia showed up a dark colour. Variety Spratt Archer. Weather bad before seeding in March, dry afterwards until June 21st, when wet weather set in. On the whole, however, the season was good with plenty of sun.

Yields per plot, as returned.
(4 acres.)

No Manure.					Sulphate of Ammonia.				
Head corn.		Tail corn.			Head corn.		Tail corn.		
qr. st.		qr. st.			qr. st.		qr. st.		
No. 1 ...	13½ —	2½	4		No. 2 ...	14½ —	4½	—	
No. 3 ...	14 4	2	7		No. 4 ...	16 —	3½	—	

Chiselborough.

Plot 1 (Sulphate of Ammonia) badly laid, rooks very troublesome. Plots 4 and 5 (both Sulphate of Ammonia) and 2, 3 and 6 (unmanured) stood up better. There were three pairs of plots, two of which were taken after wheat, following flax, following ley, all unmanured. It was very clean, undersown with clover. A little irregularity in the plants, but nothing important. The third pair, at the East end, was taken after mangolds receiving farmyard manure and

sulphate of ammonia. On July 12th the crops were all standing well in spite of the fact that there had been little sun. With sunny weather it would have ripened nicely. There was a marked difference between the unmanured and sulphate of ammonia plot. Ultimately the plot receiving sulphate of ammonia following mangolds went down badly. Badly troubled by rooks, and Mr. Clarke estimated that this plot lost quite 3 or 4 sacks. Rainfall in inches, at the nearest station, Merriott, Crewkerne, during the growing season :—

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1923 ...	1.75	8.91	1.64	2.55	1.31	0.50	0.77	2.61	2.99
1924 ...	3.65	0.64	1.72	3.43	4.61	2.90	4.05	3.45	5.37
1925 ...	3.33	3.95	0.65	2.67	3.84	0.01	2.33	2.25	3.82
1926 ...	4.08	1.83	0.48	2.75	2.02	2.45	3.46	1.27	0.78

These figures were supplied by courtesy of Mrs. C. H. Blake.

Yields per plot, as returned.
(Plots 1, 2, 2 acres; 3, 4, 5, 3 acres; 6, 2.5 acres.)

No Manure.								
Head corn.				Tail corn.				
		ton.	cwt.	qr.	lb.	cwt.	qr.	lb.
No. 2	...	2	0	3	0	2	1	0
No. 3	...	2	14	3	0	1	2	12
No. 6	...	1	10	2	4	—	2	16

Sulphate of Ammonia.								
Head corn.				Tail corn.				
		ton.	cwt.	qr.	lb.	cwt.	qr.	lb.
No. 1	...	1	18	2	14	3	4	
No. 4	...	2	15	1	14	1	3	10
No. 5	...	3	2	2	14	1	3	14

Beverley. Lime Kilns Field. Wold land with chalk subsoil.

Four plots of four acres. Previous crop, wheat manured with farmyard manure in autumn. Seed sown 23rd and 26th April. Manures applied 22nd and 24th April. 3 bushels per acre. Seedbed rather on the

was cold and wet after the barley came out Crop suffered from wireworm, but was rolled and afterwards filled out well. Cutting began August 25th.

Wye.

On June 15th the plots looked exceedingly well. They were sown with clover, which had germinated nicely. The barley was standing up clean and free from weeds and promised a heavy crop, given sunny weather. Part of the field has been folded and part not, but the plots were so arranged that each had equal areas of the folded land and of the unfolded land.

Yields per plot (4 acres) as returned.

	No Manure.				Sulphate of Ammonia.			
	qr.		st.		qr.		st.	
No. 1 ...	17	13			14½	9		
No. 3 ...	14½	8			18	6½		

wet side, but barley went in well. The winter

Yields per acre, as returned.

	No Manure				Sulphate of Ammonia.			
	Head.		Tail.		Head.		Tail.	
	bu.	lb.	bu.	lb.	bu.	lb.	bu.	lb.
No. 2 ...	50	4	6	4	47	45	7	34
No. 4 ...	51	1	6	10	48	43	10	29

BARLEY 1926. H. V. SHERINGHAM.

(*South Creak, Fakenham.*)

Medium loam. Field name: 100 Acres. Previous crop, mangolds, which received eight loads farmyard manure and 3 cwt. kainit. Land ploughed once, cultivated once, harrowed four times, rolled once, harrowed and rolled after sowing. Seed sown March 11th and 12th at the rate of 10 pecks per acre; went in well. Manures applied March 19th and 20th. Barley receiving muriate came into ear first, then sulphate, and lastly, but only a little later, the unmanured barley.

On July 16th the chloride plots looked the best, having had longer ripening period. Barley receiving sulphate showed the green colour.

Season had been dry at first, then wet, and the plots had suffered from rather a bad attack of either wireworm or frit fly.

Rothamsted Experimental Station.—Harpenden, Herts.

The experiments were carried out on two fields. New Zealand field and West Barnfield. In the former was the set of small replicated

Milling Barley Experiments—Road Piece—1926.

Plot.	Manures per Acre.	Head Corn.			Straw, Chaff, etc.			
		Bushels.	Weight. per Bushel	Tail Corn.				
1	Nothing	32.2	53.7	114	Tons. 1	cwt. 5	qr. 2	lbs. 2
2	Super: 3 cwt.; S/Potash, 1½ cwt.; S/Ammonia, 1 cwt.	48.5	52.7	252	1	16	3	8
3	Super: 3 cwt.; S/Ammonia, 1 cwt. ...	41.6	52.7	126	1	9	0	22
4	S/Potash, 1½ cwt.; S/Ammonia, 1 cwt. ...	42.9	52.3	175	1	16	0	27
5	Super: 3 cwt.; S/Potash, 1½ cwt. ...	35.3	53.4	147	1	4	2	8
6	S/Ammonia, 1 cwt.	39.3	52.1	160	1	13	3	20
7	Muriate of Ammonia = 1 cwt. S/Ammonia	47.1	52.9	148	1	13	3	13
8	Super: 3 cwt.; S/Potash, 1½ cwt.; Muriate of Ammonia — 1 cwt. S/Ammonia ...	41.1	53.1	167	1	10	3	13

plots which occupied only a small part of the field; of the remainder, part was dressed with sulphate of ammonia and part left unmanured. The field is undulating, the part receiving sulphate of ammonia being some 20 feet lower than the rest of the field. The previous crop was mangolds, which received dung and artificials. The barley germinated well and evenly, and promised to be heavy, though the sulphate of ammonia plot was rather foul. Stormy weather a few weeks before harvest laid the crop badly and harvesting was made very difficult.

West Barnfield, which had previously been cropped with mangolds and potatoes, had four plots, two of which received sulphate of ammonia and two no nitrogen. The previous crop had not been liberally manured, potatoes only being dunged. The mangolds

were a poor crop. Germination was rather uneven, and at no time did the crop look well. Little difference was apparent between the plots. Bad weather before harvest laid the crop, most damage being done where dung had been applied previously. The crop was harvested in bad conditions.

Soil.—Clay with flints.

West Barnfield drilled March 18, 1926. Rate 3 bushels/acre. Cut August 30, 1926, carted September 11th and 13th, 1926.

New Zealand, drilled March 16th, 1926. Cut August 27th, 1926, carted September 10th, 1926.

Woburn Experimental Farm, Beds., 1926. Road Piece. Clay loam.

These plots were in continuation of the

first series of experiments. Eight treatments were included and were duplicated, there being 16 plots of one-eighth of an acre. Mangolds were the previous crop, and these had received a dressing of mixed artificials, but no dung. The field was drilled on the 19th March, at the rate of 3 bushels to the acre, the manures being applied on the same day. The seed went in well and the fully manured plots were later considered to look better than those unmanured and lacking nitrogen. The crop was good but slightly damaged.

Harper Adams Agricultural College, Newport, Salop.—Strong loam.

The experiment here was also in continuation of the small-scale series. The previous crop was rape, cut and carried, receiving two tons of lime, following mangolds heavily manured. Germination was good, and the crop looked well in the early stages. No differences attributable to manuring could be observed. All plots were badly laid, and harvesting was very difficult.

Harper Adams Agricultural College, Newport, Salop.
1925 Malting barley results, received too late for inclusion in the 1925 report.

Plot No.	Treatment.	Yield of dressed grain in bushels per acre. Mean.		Tail corn.	Total.
1	No manure ...	36.2		1.9	38.1
1a	„ ...	33.0	34.6	1.4	34.4
2	Complete manure	37.1		1.9	39.0
2a	„ ...	47.3	42.2	2.3	49.5
3	No potash ...	39.6		1.4	41.0
3a	„ ...	36.7	38.2	2.1	38.8
4	No phosphate	23.9		1.8	25.7
4a	„ ...	40.0	31.9	1.9	41.9
5	No nitrogen ...	21.4		0.7	22.1
5a	„ ...	33.0	27.2	1.9	34.9
6	Nitrogen only	44.3		3.3	47.6
6a	„ ...	36.7	40.5	1.8	38.5

Harper Adams Agricultural College, Newport, Salop.

Season 1926.

(Six plots in duplicate, i.e., 12 plots in all. Area of each plot—one-twelfth of an acre.)

Plot No.	Treatment.	Weights per plot corn (lb.)		Total.	Straw (cwt.)	Yields per acre. Bushels.			Mean yield.	
		Head.	Tail.			Head.	Tail.	Total.	Head.	Tail.
1	No manure ...	150½	32	182½	2½	32.2	6.83	39.03		
1a	„ ...	157	58	215	3½	32.6	12.4	45.0	32.4	9.6
2	Complete artificials ...	205	32½	237½	2½	43.9	6.86	50.76		
2a	„ ...	184½	46½	231	3	39.4	9.95	49.35	41.6	8.4
3	No potash ...	204½	48	252½	3½	43.9	10.3	54.2		
3a	„ ...	174	35½	209½	3	37.3	7.6	44.9	40.6	9.0
4	No phosphate ...	193	41½	234½	2½	41.4	8.85	50.25		
4a	„ ...	232	37½	269½	3	49.7	8.2	57.9	45.6	8.5
5	No nitrogen ...	196	48½	244½	3½	42.0	10.2	52.2		
5a	„ ...	187½	50	237½	3½	40.2	10.7	50.9	41.1	10.5
6	Nitrogen only ...	133	61	194	3½	28.5	13.1	41.6		
6a	„ ...	177½	46½	223½	3½	38.0	9.9	47.9	33.3	11.5

N.B.—All plots very badly laid by weather, and difficult to mow, even with a scythe.

THE INSTITUTE OF BREWING RESEARCH SCHEME.

THE BARLEY EXPERIMENTS OF 1926.

MALTING AND ANALYTICAL RESULTS.

By H. M. LANCASTER and H. LLOYD HIND, B.Sc., F.I.C.

Large Plots.—The barleys from nine of the twelve centres at which two acre plots were grown (for description of seed, see p. 307) were malted in bulk at the floor maltings of Gilstrap, Earp & Co., Ltd., Newark, and William Younger & Co., Ltd., Edinburgh. At Newark the barley from each plot at eight centres was malted separately, thirty-six steeps in all, the quantities varying between seven and twenty-five quarters. The barleys from the duplicate plots at Dunbar were bulked and malted together at Edinburgh. All the barleys were sweated at the maltings. The maltsters report that no differences were noticed in the behaviour on the floors of manured and unmanured barleys.

Samples of most of the sweated barleys were drawn previous to steeping and malted by the experimental stocking method at Messrs. Fuller Smith & Turner's Malting, where the work has been carried on for the last five years. This duplication was intended to provide a substantial basis for comparison of malts made from the same barley in the usual commercial manner, and in experimental stockings. It was also designed to give information on the validity of stocking malting as a method for determining the malting value of barley. This question will be dealt with separately.

The barleys from Fakenham, Nynhead and Wye were not malted in bulk. Samples were sweated at Rothamsted by keeping them in small bulk for about four days in a room maintained at about 80° Fahr. and until the moisture had been reduced to about 11 per cent. 1,200 grms. of the raw barley was taken in each case and the sweated barley from this forwarded to Chiswick for malting. The malting loss was determined from the weight of dry cleaned malt obtained from the original 1,200 grms. of raw barley. It therefore included loss incurred during sweating.

Stocking Malting.—The samples of sweated barley from both large and small plots were malted in quadruplicate, four stockings being made up from each sample and steeped at intervals of about a week. The steeping period was 50 hours at a temperature of 50° to 52° F. The stockings were placed in a floor of growing barley as described in previous reports and germinated as usual. The flooring temperatures averaged 59° F. and did not exceed 62° F. Kilning was carried out rather slowly and at low temperatures to obtain pale malts. The finished malts from the four stockings were finally bulked.

In order to obtain definite information of the differences produced in the same barley when malted in stockings and bulk, under otherwise identical conditions, a special control was carried out in the following way on a floor alongside that on which the experimental barleys were being grown in stockings immersed in the same barley.

Four stockings of the barley being malted in bulk were made up and the malting carried through in a floor of the same barley. The "stocking" malt produced and a sample of the bulk in which it had been grown and kilned were analysed, and the following differences found.

The "stocking" malt showed an average of 1 lb. less extract and an average malting loss of 0.7 per cent. higher than the bulk.*

A comparison of brewers' extract and cold water extract between floor and "stocking" malts from the same barley is given below. The figures given are the averages of the extract and C.W.E., respectively found for the four, or, in some cases, six or two, malts made from the barleys from the separate plots on each farm. It seems probable that the rather slow and cool drying, together with some lack of aeration in

* In the tables 0.7 per cent. has, therefore, been deducted from the malting loss actually obtained with the experimental malts to make the results more comparable with what might have been expected if the barleys had been malted in bulk. No allowance has, however, been made for extract in these tables.

the stockings, account for the high cold water extracts in the "stocking" malts. The flooring temperatures averaged 59°F., and never exceeded 62°F. Averaged over the whole of the 36 samples referred to in this table the difference in extract was 0.3 lb. in favour of the bulk malts. (Table 1).

In cases in which the barleys were damaged in threshing the letter D follows the valuation, indicating that so far as could be judged the barley would have had the value indicated if not damaged. In cases in which the damage was very marked in the malt, it was found impossible to assess them

TABLE 1.

Locality.	Extract lb. per quarter on dry malt.			Cold water extract %	
	Bulk	Stocking	Difference	Bulk	Stocking
<i>Malted at Newark</i>					
Dunmow	100.0	99.9	-0.1	19.3	21.9
Cawkwell (Spratt-Archer seed) ..	97.3	97.9	+0.6	19.3	22.6
Wellingore	100.3	98.5	-1.8	19.8	23.4
Chiselborough	100.7	100.4	-0.3	18.3	19.4
Beverley	98.8	97.8	-1.0	18.7	22.0
Longniddry	101.6	100.5	-1.1	18.3	19.7
Rothamsted	98.8	99.0	+0.2	17.8	20.3
Sprowston	98.5	99.3	+0.8	18.3	20.9
<i>Malted at Edinburgh.</i>					
Dunbar	99.8	100.1	+0.3	19.5	19.6

As a whole, the barleys were good and malted well. Those from Dunbar, Longniddry, Nynehead, Chiselborough and Wellingore were extremely good, and those from Dunmow exceptional in that rather poor-looking barley made good malt, a remark which, as in previous years, applies to the barley from Cawkwell.

ANALYTICAL AND MALTING RESULTS.

TABLE 2.

The analytical determinations of which the results are given were carried out by the standard methods laid down by the Malt Analysis Committee of the Institute, in so far as the latter were applicable. The moistures of the barleys malted in bulk were determined at the maltsters' laboratories. The tables also include the valuations of the Barleys and Malts as determined by the Valuation Sub-Committee. The bulk malts had been dressed at the maltings previous to valuation, but the "stocking" malts were only rubbed over a sieve. This accounts to some extent for the lower valuation of the latter.

as undamaged. The value given is that adjudged for the condition in which they actually existed. Such cases are also marked D. The mean of duplicate plots is given for comparison between manured and unmanured plots.

It will be noted that the malting loss given for barleys sweated at the maltings does not include sweating loss and, as the latter was not known, the extract could not be calculated to 448 lb. raw barley.

Two sets of figures are given for the malt analyses. Those in ordinary type in the following tables refer to malts made in stockings. Those in italic type refer to bulk malting. Both malts were made from the same barley after sweating at the maltings.

The manurial treatments are expressed as follows:—

No manure	O
Sulphate of Ammonia	S
Muriate of Ammonia	M

TABLE 2.—BULK BARLEYS.

"Stocking" Malts in ordinary type.

Bulk Malts in *italic* type.

D after valuation indicates damaged grain.

No.	Treatment.	Barley.				Malt.					Market valuation by sub-committee. Shillings.		
		Moisture per cent.	1,000 corn weight (grms.) dry.	Nitrogen per cent. on dry.	Malting loss per cent. on dry.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic Power Lintner.	Cold water Extract per cent.	Barley, 448 lb., Nov., 1926.	Malt, 336 lb., Dec., 1926.	
SIR HARRY HOPE, DUNBAR.													
Good red soil.													
1	O	16.9	39.7	1.516	7.5	3.1	100.1	4.0	43.5	20.1	46/-	71/-	
					9.9	1.2	100.2	6.5	27.2	19.6		80/-	
2	S	16.7	40.9	1.536	7.7	3.3	100.2	4.0	42.7	19.2	46/-	72/-	
					10.2	1.5	99.5	8.5	29.5	19.4		85/-	
W. HASLER, DUNMOW, ESSEX.													
Medium to heavy clay loam.													
3	O	17.8	37.5	1.595	8.6	3.2	99.5	4.2	53.3	22.0	43/-	63	
						1.7	99.7	4.7	34.5	19.5		71/-	
4	O	17.4	36.4	1.476	8.4	3.0	100.5	3.8	52.5	21.5	44/-	63/-	
						1.4	100.4	5.7	29.0	18.7		69/-	
5	S	17.7	37.6	1.463	9.0	2.8	99.9	4.3	46.6	22.1	47/-	61/-	
						1.4	100.2	5.0	33.9	19.9		69/-	
6	S	17.2	37.3	1.552	9.2	2.8	99.9	4.5	49.4	22.2	44/-	61/-D	
						1.4	100.1	4.0	36.4	19.0		70/-	
Mean	O	17.6	36.9	1.535	8.5	3.1	100.0	4.0	52.9	21.7	43/-	63/-	
						1.5	100.0	5.2	31.7	19.1		70/-	
	S	17.4	37.4	1.507	9.1	2.8	99.9	4.4	48.0	22.1	45/-	61/-	
						1.4	100.1	4.5	35.1	19.4		69/-	
A. E. DAVY, CAWKWELL.*													
Loam over Chalk.													
7	O	18.4	29.8	1.749	10.5	2.9	96.3	5.3	52.9	23.7	38/-	55/-	
						1.3	95.9	4.7	34.5	18.9		60/-	
8	O	17.6	31.3	1.577	9.8	3.1	99.1	4.8	45.0	22.6	40/-	58/-D	
						1.4	97.6	8.5	25.0	19.4		55/-D	
9	S	17.8	30.4	1.811	9.5	3.0	97.6	4.5	48.3	21.8	38/-	52/-	
						1.2	96.6	4.7	42.5	19.5		56/-	
10	S	18.5	31.2	1.618	9.2	2.8	98.6	4.5	47.6	22.3	40/-	57/-	
						1.4	99.0	6.0	33.0	19.6		60/-	
Mean	O	18.0	30.5	1.663	10.1	3.0	97.7	5.0	48.9	23.1	39/-	56/-	
						1.3	96.7	6.6	29.7	19.1		57/-	
	S	18.1	30.8	1.714	9.3	2.9	98.1	4.5	47.9	22.0	39/-	45/-	
						1.3	97.8	5.3	37.7	19.5		58/-	

* Spratt-Archer seed.

TABLE 2 (Continued).

No.	Treatment.	Barley.				Malt.				Market valuation by sub-committee. Shillings.			
		Moisture per cent.	1,000 corn weight (grms.) dry.	Nitrogen per cent. on dry.	Making loss per cent. on dry.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic Power Lintner.	Cold water Extract per cent.	Barley, 448 lb., Nov., 1926.	Malt, 336 lb., Dec., 1926.	
G. H. NEVILLE, WELLINGORE, LINCS.													
Lincoln Heath, light loam.													
11	O	18.6	30.2	1.361	9.6	3.0 1.5	98.4 100.3	5.5 3.7	39.2 35.0	23.4 19.7	43/-	60/- 68/-	
12	O	17.1	32.3	1.432	10.5	3.1 1.5	98.3 99.7	5.0 6.0	41.7 26.3	23.2 19.4	42/-	53/-D 65/-D	
13	S	16.5	31.9	1.425	10.3	3.3 1.4	98.6 100.3	5.3 4.2	41.7 33.3	23.6 20.4	45/-	54/-D 65/-D	
14	S	17.1	34.1	1.315	10.3	3.0 1.4	98.8 100.9	5.7 4.5	43.5 30.3	23.4 19.9	46/-	62/- 70/-	
Mean	O	17.8	31.2	1.396	10.0	3.0 1.5	98.3 100.0	5.2 4.8	40.4 30.6	23.3 19.5	42/-	56/- 66/-	
	S	16.8	33.0	1.370	10.3	3.1 1.4	98.7 100.6	5.5 4.3	42.6 31.8	23.5 20.1	45/-	58/- 67/-	

R. A. CLARKE & SONS, CHISELBOROUGH, STOKE-UNDER-HAM, SOMERSET.

Light sandy soil.

16	O	17.9	36.6	1.430	7.3	2.9 1.6	100.8 100.8	3.2 3.2	46.0 34.5	19.5 18.3	58/-	85/-	84/-
18	O	19.0	35.7	1.461	6.3	2.7 1.6	100.4 100.8	3.2 4.0	46.0 27.0	19.1 18.2	56/-	80/-	81/-
20	O	17.7	38.6	1.414	10.0	3.1 1.7	100.7 101.8	3.2 3.5	46.0 34.5	18.9 18.2	55/-	80/-	83/-
15	S	19.0	34.2	1.542	7.7	2.7 1.3	99.2 98.8	3.5 5.7	57.0 25.0	20.5 18.3	42/-	62/-	70/-
17	S	18.4	34.2	1.483	7.7	2.7 1.6	100.9 100.9	3.0 3.2	46.0 33.3	18.9 18.7	55/-	85/-	88/-
19	S	17.9	34.8	1.437	7.0	2.8 1.9	100.2 101.1	3.2 3.2	46.0 44.0	19.3 18.3	49/-	71/-	81/-
Mean	O	18.2	37.0	1.435	7.9	2.9 1.6	100.6 101.1	3.2 3.6	46.0 32.0	19.2 18.2	56/-	82/-	83/-
	S	18.4	34.4	1.487	7.5	2.7 1.6	100.1 100.3	3.2 4.0	49.7 34.1	19.6 18.4	49/-	73/-	80/-

H. V. SHERINGHAM, FAKENHAM, NORFOLK.

Medium loam.

21	O	18.5	33.4	1.466	8.3	3.2	99.4	3.5	34.2	19.4	44/-	63/-	
22	S	18.3	32.7	1.492	8.4	2.9	98.6	3.7	37.4	20.2	40/-	62/-	
23	M	18.7	36.4	1.562	7.7	2.9	98.1	3.5	34.4	19.4	42/-	72/-	

(No bulk malting.)

TABLE 2 (continued).

No.	Treatment.	Barley.					Malt.					Market valuation by sub-committee. Shillings.	
		Moisture per cent.	1,000 corn weight (grms.) dry.	Nitrogen per cent. on dry.	Malting loss per cent. on dry.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic Power Lintner.°	Cold water Extract per cent.	Barley, 448 lb., Nov., 1926.	Malt, 336 lb., Dec., 1926.	
NORFOLK AGRICULTURAL STATION, SPROWSTON, NORWICH.													
<i>Sandy loam, overlaying brick earth.</i>													
25	O	19.2	33.2	1.424	7.6	2.9 1.4	99.7 99.0	3.3 3.2	50.5 26.3	20.2 17.7	40/- 70/-	60/- —	
26	O	19.1	34.0	1.471	—	1.4	99.7	3.7	27.0	18.4	41/-	63/-	
27	S	19.5	33.8	1.003	7.8	3.2 1.2	99.0 98.2	4.0 5.5	55.5 32.8	21.7 19.0	38/-	58/- 58/-	
28	S	18.5	34.3	1.643	—	— 1.3	— 97.0	— 4.5	— 26.3	— 17.8	39/-	— 62/-	
Mean	O	19.1	33.6	1.447	7.6	1.4	99.3	3.4	26.6	18.0	40/-	66/-	
	S	19.0	34.0	1.623	7.8	1.2	97.6	5.0	29.5	18.4	38/-	60/-	

26 and 28 not malted in stocking.

S. H. SPILMAN, BEVERLEY, YORKS.

Wold land, chalk subsoil.

29	O	17.0	36.5	1.510	11.0	3.1	98.8	5.5	50.0	24.2	38/-	52/-D
						1.2	99.5	7.0	21.7	19.4		61/-
30	O	17.2	35.0	1.483	10.2	2.9	98.1	5.3	58.5	22.5	37/-	52/-
						1.1	99.1	7.0	23.8	17.9		64/-D
31	S	16.9	33.1	1.578	10.1	2.9	97.7	5.3	57.5	23.2	38/-	52/-
						1.3	99.0	9.7	19.2	19.3		61/-
32	S	17.2	32.4	1.566	9.3	2.9	96.6	4.3	61.0	21.5	37/-	53/-
						1.0	97.4	6.7	30.3	18.3		60/-
Mean	O	17.1	35.7	1.496	10.6	3.0	98.4	5.4	54.2	23.4	37/-	52/-
						1.1	99.3	7.0	22.7	18.6		62/-
	S	17.0	32.7	1.572	9.7	2.9	97.1	4.8	59.2	22.3	37/-	52/-
						1.1	98.2	8.2	24.7	18.8		60/-

W. BRUCE & SON, LONGNIDDRY, E. LOTHIAN.

33	O	17.2	37.5	1.395	7.5	3.4	101.2	3.0	50.0	19.4	44/-	71/-
						1.3	101.6	5.0	28.6	18.1		75/-D
34	O	17.7	38.9	1.366	—	—	—	—	—	—	50/-	—
						1.5	102.3	3.5	30.3	17.6		79/-
35	S	17.3	35.6	1.466	7.3	3.2	99.9	3.3	58.0	20.1	42/-	58/-D
						1.3	100.7	6.5	26.3	18.6		66/-
36	S	17.6	38.3	1.383	—	—	—	—	—	—	46/-	—
						1.6	101.7	3.7	40.0	18.8		67/-D
Mean	O	17.4	38.2	1.380	7.5	1.4	101.9	4.2	29.4	17.8	47/-	77/-
	S	17.4	36.9	1.424	7.3	1.4	101.2	5.1	33.1	18.7	44/-	66/-

34 and 36 not malted in stocking.

TABLE 2 (continued).

No.	Treatment.	Barley.					Malt.					Market valuation by sub-committee. Shillings.	
		Moisture per cent.	1,000 corn weight (grms.) dry.	Nitrogen per cent. on dry.	Making loss per cent. on dry.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic Power Lintner.°	Cold water Extract per cent.	Barley, 448 lb., Nov., 1926.	Malt, 336 lb., Dec., 1926.	
L. MORTIMER, NYNEHEAD, SOMERSET.													
<i>Red, light, good barley soil.</i>													
37	O	17.5	39.7	1.412	7.4	3.3	99.6	3.2	49.0	19.3	49 -	81/-	
38	O	17.4	40.9	1.409	7.4	2.7	98.6	3.2	48.0	19.7	53/-	80/-	
39	S	16.4	36.9	1.417	8.6	2.8	99.0	3.0	51.0	21.0	47/-	65/-	
40	S	16.9	38.4	1.369	8.9	3.1	100.4	4.0	47.0	22.1	50/-	60/-	
Mean	O	17.4	43.3	1.440	7.4	3.0	99.1	3.2	48.5	19.5	51/-	80/-	
	S	16.6	37.6	1.393	8.7	2.9	99.7	3.5	49.0	21.5	48/-	62/-	

Not malted in bulk.

ROTHAMSTED AGRICULTURAL STATION, HARPENDEN, HERTS.

*Heavy strong soil, clay with flints.**West Barn Field.*

41	O	18.4	39.6	1.531	7.3	3.2	99.0	4.5	54.5	20.1	40/-	57/-D
						1.5	99.2	5.7	27.8	17.7		57/-D
42	O	18.6	40.6	1.624	—	—	—	—	—	—	38/-	—
						1.1	98.1	5.2	28.6	17.4		62/-D
43	S	18.1	38.1	1.751	7.0	3.1	99.1	4.3	57.0	20.5	38/-	58/-D
						1.5	99.0	5.7	25.0	18.0		62/-D
44	S	19.3	38.2	1.573	—	—	—	—	—	—	39/-	—
						1.3	98.9	5.7	25.6	17.4		60/-
Mean	O	18.5	40.1	1.577	7.3	1.3	98.6	5.4	28.2	17.5	39/-	59/-
	S	18.7	38.1	1.662	7.0	1.4	98.9	5.7	25.3	17.7	38/-	61/-

*42 and 44 not malted in stocking.**New Zealand Field.*

45	O	17.8	39.7	1.619	—	1.4	99.1	6.0	31.8	19.0	38/-	60/-
46	S	17.0	36.9	1.560	—	1.3	99.2	6.0	32.3	19.6	39/-	57/-D

Not malted in stocking. These two are not strictly comparable, see p. 119.

SOUTH EASTERN AGRICULTURAL COLLEGE, WYE, KENT.

Kent loam, overlying chalk.

47	O	17.4	38.7	1.560	10.2	3.3	99.0	5.5	46.0	22.3	44/-	58/-
48	O	16.2	42.2	1.592	10.8	3.4	99.3	6.3	46.5	23.0	48/-	58/-D
49	S	17.4	36.6	1.567	9.8	3.6	97.3	4.3	61.5	22.1	46/-	53/-D
50	S	17.3	40.2	1.572	10.1	3.2	97.6	6.3	49.0	22.9	42/-	58/-D
Mean	O	16.8	40.4	1.576	10.5	3.3	99.1	5.9	46.2	22.6	46/-	58/-
	S	17.3	38.4	1.569	9.9	3.4	97.4	5.3	56.2	22.5	44/-	55/-

Not malted in bulk.

BARLEYS GROWN ON THE SMALL PLOTS.

TABLE 3.

In the following table will be found the results obtained from the barleys grown on small plots. They were malted in experimental stockings as previously described. The averages given for each centre refer to plots 1 to 5.

The manurial treatment of the plots was the same as in previous years, and as follows:—

Plot 1. No manure.

2. Complete artificials (1 cwt. sulphate of ammonia, 3 cwt. superphosphate, 1½ cwt. sulphate of potash per acre).

3. Artificials without potash (1 cwt. sulphate of ammonia, 3 cwt. superphosphate per acre).

4. Artificials without phosphate (1 cwt. sulphate of ammonia, 1½ cwt. sulphate of potash per acre).

5. Artificials without nitrogen (3 cwt. superphosphate, 1½ sulphate of potash per acre).

N. Nitrogen only (1 cwt. sulphate of ammonia per acre).

Muriate of ammonia was used for Nos. 74 and 87 in place of sulphate of ammonia, at a rate calculated to give the same quantity of nitrogen.

No. 75. Muriate of ammonia was used with superphosphate and sulphate of potash.

86. Muriate of potash was used.

The manurial treatments of the Rothamsted permanent barley plots are given at the foot of the table.

TABLE 3.

BARLEYS GROWN ON SMALL PLOTS.

No.	Plot.	Barley.						Malt.				Market valuation by sub-committee.	
		Moisture per cent.	1,000 corn weight (grms., dry.)	Nitrogen per cent. on dry.	Maltng loss per cent. on dry.	Extract calculated to 445 lb. raw.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Dustlike Power Lintner's	Cold Water Extract per cent.	Barley 448 lb. Nov., 1926.	Malt. 336 lb. Dec., 1926.
43	1	18.1	34.3	1.510	9.4	98.5	3.28	99.5	4.5	44.5	22.5	43/-	57/-
44	2	17.6	32.0	1.561	9.9	97.5	2.92	98.5	4.8	48.5	22.4	41/-	56/-
45	3	17.4	32.4	1.401	10.3	97.3	2.78	98.6	5.0	44.0	23.4	41/-	58/-
46	4	17.6	32.3	1.509	10.1	97.2	2.50	98.4	6.0	43.0	23.4	41/-	55/-
47	5	18.0	34.0	1.403	9.9	97.8	2.42	99.3	6.2	41.0	25.1	44/-	57/-
47N	N	17.9	31.9	1.458	10.0	97.9	3.18	99.5	5.8	46.5	22.9	42/-	53/-
Average	45—47	17.7	33.0	1.489	9.9	97.5	2.78	98.9	5.4	44.2	23.4	42/-	57/-

NORFOLK EXPERIMENTAL STATION, SPROWSTON, NORWICH.

Light loam, overlying gravel.

43	1	18.1	34.3	1.510	9.4	98.5	3.28	99.5	4.5	44.5	22.5	43/-	57/-
44	2	17.6	32.0	1.561	9.9	97.5	2.92	98.5	4.8	48.5	22.4	41/-	56/-
45	3	17.4	32.4	1.401	10.3	97.3	2.78	98.6	5.0	44.0	23.4	41/-	58/-
46	4	17.6	32.3	1.509	10.1	97.2	2.50	98.4	6.0	43.0	23.4	41/-	55/-
47	5	18.0	34.0	1.403	9.9	97.8	2.42	99.3	6.2	41.0	25.1	44/-	57/-
47N	N	17.9	31.9	1.458	10.0	97.9	3.18	99.5	5.8	46.5	22.9	42/-	53/-
Average	45—47	17.7	33.0	1.489	9.9	97.5	2.78	98.9	5.4	44.2	23.4	42/-	57/-

HARPER ADAMS AGRICULTURAL COLLEGE, NEWPORT, SALOP.

Sandy loam.

53	1	17.4	36.7	1.651	11.3	95.7	3.30	97.8	9.0	54.0	22.6	39/-	51/-
54	2	16.9	37.7	1.539	11.7	97.7	3.16	99.8	5.0	54.5	21.0	40/-	58/-
55	3	17.2	37.4	1.492	12.4	95.9	3.36	99.2	5.3	48.5	21.0	40/-	53/-
56	4	16.8	38.5	1.420	11.0	98.8	3.14	101.0	4.3	46.5	20.4	45/-	58/-
57	5	17.3	37.2	1.430	10.1	99.0	3.14	100.0	5.3	51.0	22.3	40/-	54/-
57N	N	16.3	35.3	1.553	10.9	96.8	3.24	98.5	6.3	51.5	21.8	40/-	54/-
Average	53—57	17.1	37.5	1.506	11.4	97.4	3.22	99.6	5.8	50.9	21.5	41/-	55/-

TABLE 3 (continued).

No.	Plot.	Barley.					Malt.					Market valuation by sub-committee.	
		Moisture per cent.	1,000 corn weight (grms.) dry.	Nitrogen per cent. on dry.	Malting loss per cent. on dry.	Extract calculated to 448 lb. raw.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic Power Linkner°	Cold Water Extract per cent.	Barley 448 lb. Nov. 1926.	Malt. 336 lb. Dec., 1926.
WOBBURN EXPERIMENTAL FARM, BEDS.													
Sandy loam.													
68	1	16.2	36.2	1.522	8.7	101.0	3.42	99.1	4.0	49.5	22.4	46/-	60/-
69	2	15.9	35.6	1.598	10.2	97.1	3.44	97.7	4.5	66.5	23.5	40/-	52/-
70	3	16.1	33.7	1.545	10.0	97.8	3.42	98.2	3.7	62.5	22.1	42/-	54/-
71	4	16.3	35.3	1.625	9.7	99.0	3.26	98.8	4.0	62.5	22.4	41/-	58/-
72	5	15.7	37.6	1.513	9.6	100.8	3.22	100.0	3.2	53.5	20.9	46/-	65/-D
73	N	16.7	34.1	1.610	8.9	99.8	3.02	98.4	4.0	62.5	21.1	39/-	52/-
74	AmCl.	16.1	35.8	1.449	9.6	100.7	3.16	99.6	4.2	48.5	21.7	45/-	60/-D
75	Super.K. AmCl.	16.3	36.6	1.491	8.6	101.3	3.10	99.4	3.5	53.0	20.8	41/-	62/-
Average	68—72	16.0	35.7	1.561	9.6	99.1	3.35	98.8	3.9	58.9	22.3	43/-	58/-

ROTHAMSTED EXPERIMENTAL STATION, HARPENDEN, HERTS.

Heavy strong soil, clay with flints. New Zealand Field.

81	1	17.0	38.4	1.604	9.8	98.4	3.16	98.6	5.0	50.0	22.2	40/-	57/-D
82	2	17.0	38.8	1.711	9.9	97.6	2.92	97.9	5.2	51.5	22.2	39/-	54/-D
83	3	16.9	37.3	1.673	9.6	97.7	3.06	97.5	4.3	58.0	23.0	39/-	52/-
84	4	17.5	37.1	1.710	9.0	98.3	3.08	98.2	4.5	51.5	21.8	39/-	56/-
85	5	17.0	38.4	1.599	9.8	98.1	2.94	98.3	5.0	55.0	22.3	41/-	53/-
86	KCl	17.4	36.4	1.726	9.3	97.7	3.08	97.9	4.5	53.0	22.3	39/-	54/-
87	AmCl.	17.2	36.8	1.684	9.3	98.3	3.14	98.2	6.2	54.0	22.4	39/-	51/-
88	N	17.0	36.9	1.683	9.8	98.0	3.50	98.2	5.3	59.5	22.9	39/-	57/-
Average	81—85	17.1	38.1	1.659	9.6	98.0	3.03	98.1	4.8	53.2	22.3	40/-	54/-

ROTHAMSTED, GREAT HOOS FIELD, PERMANENT BARLEY PLOTS.

93	O 1	18.3	34.7	1.609	11.2	94.4	3.16	97.8	5.7	47.0	23.4	37/-	53/-
94	O 2	17.7	37.3	1.541	10.3	98.0	3.00	99.6	5.7	46.5	23.7	45/-	56/-D
95	O 3	17.7	33.4	1.597	11.6	94.4	2.92	97.3	6.7	47.0	25.0	37/-	51/-D
96	O 4	17.8	36.8	1.630	10.7	96.6	3.02	98.5	6.7	52.0	24.3	38/-	52/-
97	A 1	17.6	35.9	1.724	11.0	94.8	3.28	97.1	5.3	59.0	23.7	38/-	52/-
98	A 2	17.8	34.7	1.646	10.1	97.1	2.92	98.5	5.7	49.0	23.2	39/-	52/-
99	A 3	18.0	34.4	1.810	11.7	92.2	2.66	95.7	7.5	59.5	24.4	37/-	51/-
100	A 4	18.7	34.7	1.547	10.0	97.6	2.96	99.1	5.2	50.5	23.7	39/-	53/-
101	AA 1	17.4	37.3	1.818	11.0	96.6	2.96	96.6	5.7	60.5	23.2	37/-	51/-
102	AA 2	17.7	34.4	1.610	10.2	97.2	3.00	98.7	5.5	53.0	24.2	39/-	53/-
103	AA 3	17.9	34.2	1.789	12.4	91.2	2.98	95.5	8.2	56.0	24.6	37/-	51/-
104	AA 4	18.8	35.7	1.608	10.7	95.5	2.64	98.9	6.2	50.5	22.6	39/-	53/-
109	7—1	17.9	36.1	1.595	11.8	95.0	3.18	98.5	6.5	49.0	23.0	39/-	54/-D
110	7—2	17.8	38.0	1.761	10.5	95.2	3.26	97.2	5.5	59.5	22.6	40/-	54/-
112	6—1	18.4	37.0	1.751	10.6	94.3	3.12	97.6	5.7	50.5	23.7	38/-	53/-

Manurial Treatments.—For complete statement see "Memoranda of Field Experiments," Rothamsted.

O 1 Nil.

O 2 Super only.

O 3 Minerals without super.

O 4 Complete minerals (super, K_2SO_4 , Na_2SO_4 , M_2SO_4)A 1 Ammonium salts alone. Am_2SO_4 and AmCl.

A 2 Super and ammonium salts.

A 3 Alkali salts.

A 4 Complete minerals and ammonium salts.

AA 1 Nitrate of soda alone.

AA 2 " " and super.

AA 3 " " and alkali salts.

AA 4 " " and complete salts.

7—1 Nil since 1871.

7—2 Dung since 1851.

6—1 Nil.

EXTENDED NITROGEN TRIALS.—NORFOLK AGRICULTURAL STATION.

In order further to test the results of nitrogenous manures in reference to yield and quality of barleys, trials were made at the Norfolk Agricultural Station, Sprowston, Norwich, with Plumage Archer and New Cross on plots with increasing quantities of sulphate of ammonia, up to the excessive amount of 3 cwt. per acre. The following table gives the results obtained and indicates that with reasonable manurial treatment up to 1 or even 1½ cwt. sulphate of ammonia

per acre, balanced with other manures, there is no depreciation in valuation, rise in nitrogen content or loss of extract of malt. When sulphate of ammonia is used alone (unbalanced manuring) a slight depreciation may be noticed at 1½ cwt. sulphate of ammonia per acre. In all cases excessive nitrogenous manuring, 3 cwt. per acre, produced marked depreciation. The marked increase in diastatic power with nitrogen content and lowered extract of malt from barleys grown under the latter conditions will be noted.

TABLE 4.
NORFOLK AGRICULTURAL STATION
NITROGEN SET.

No.	Treatment.	Barley.					Malt.					Market valuation by Sub-Committee. Shillings.	
		Moisture per cent.	1,000 corn weight (grms.) dry.	Nitrogen per cent. on dry.	Malting loss per cent. on dry.	Extract calcu- lated to 448 lb. raw.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic Power. Lintner.	Cold water extract per cent.	Barley, 448 lb., Nov., 1926.	Order of quality of barley. Malt, 336 lb., Dec., 1926.
Plumage Archer. Balanced manures, with Phosphate and Potash.													
120	Control.	16.60	33.9	1.573	—	—	3.4	98.2	5.8	46.0	24.1	38/-	2 54/-
121	½ cwt. S/Am.	16.54	33.9	1.516	—	—	3.5	98.6	5.0	46.0	23.9	38/-	1 55/-
122	1 cwt. S/Am.	16.36	33.0	1.511	—	—	3.1	97.8	6.0	49.3	23.3	38/-	3 54/-
123	1½ cwt. S/Am.	16.38	32.5	1.508	—	—	2.9	98.2	6.8	48.6	25.4	37/-	4 54/-
124	3 cwt. S/Am.	16.36	31.5	1.754	—	—	3.4	96.0	5.7	51.3	24.5	37/-	5 52/-D
Unbalanced. S/Am. only.													
125	½ cwt. S/Am.	16.82	34.6	1.557	—	—	3.3	97.5	5.3	46.6	23.3	38/-	2 55/-D
126	1 cwt. S/Am.	16.20	34.8	1.633	—	—	3.3	97.3	7.2	46.0	24.3	38/-	1 54/-
127	1½ cwt. S/Am.	16.60	34.2	1.644	—	—	3.3	97.4	6.8	50.0	23.8	37/-	3 54/-
128	3 cwt. S/Am.	16.20	32.8	1.768	—	—	3.3	95.3	4.5	66.6	23.3	37/-	4 53/-
Plumage Archer.													
129	Spring sown.	17.04	33.2	1.632	12.4	92.9	3.1	96.0	8.0	37.0	27.1	38/-	53/-
130	Autumn sown.	16.94	39.2	1.421	10.0	99.7	3.2	100.1	5.8	35.1	22.9	62/d	67/-D
New Cross.													
Balanced													
131	Control.	16.40	31.6	1.546	9.8	97.6	2.9	97.2	6.5	37.4	24.0	39/-	2 55/-
132	½ cwt. S/Am.	17.02	31.9	1.483	9.9	96.9	2.9	97.2	5.0	35.3	23.5	39/-	5 54/-
133	1 cwt. S/Am.	16.40	32.2	1.515	10.0	97.0	2.8	97.7	7.0	36.0	24.7	39/-	1 56/-D
134	1½ cwt. S/Am.	16.30	31.9	1.546	10.7	97.3	3.1	97.6	7.0	38.5	24.6	39/-	3 55/-D
135	3 cwt. S/Am.	16.42	31.7	1.639	11.0	95.6	2.8	96.4	6.8	46.0	24.0	39/-	4 54/-D
Unbalanced.													
136	½ cwt. S/Am.	16.90	33.2	1.471	9.9	98.7	3.1	98.9	5.0	32.8	22.9	39/-	1 55/-
137	1 cwt. S/Am.	16.58	32.3	1.540	10.1	98.1	2.9	97.9	5.0	35.4	23.5	39/-	2 55/-
138	1½ cwt. S/Am.	16.40	31.7	1.622	10.7	96.9	3.0	97.4	6.8	36.0	25.5	39/-	3 54/-D
139	3 cwt. S/Am.	16.50	30.9	1.834	11.4	93.3	3.0	94.9	5.0	47.0	24.0	37/-	4 53/-

BARLEYS FROM THE NATIONAL INSTITUTE OF AGRICULTURAL BOTANY, CAMBRIDGE.

As in previous years, the Barley Research Committee has acted in conjunction with the National Institute of Agricultural Botany, assisting the latter body in their Variety trials by valuing the barley, malting it, and analysing and valuing the malts produced. The malting was carried out

by the stocking method only, as just described in reference to the farmers' barleys, and similar remarks apply to the results tabulated.

Barley of different varieties was grown in trials on Dr. Beaven's "half-drill strip" method at six centres, Long Sutton (Hants.), Leegomery (Salop), Cambridge, Sprowston, Good Easter, near Chelmsford, and Newton Abbot. Each trial consisted of ten 1/80

acre strips of the variety concerned, alternating with ten similar strips of the Control variety, Plumage Archer, 1924. Most of the varieties under trial were grown at all the centres, but some were grown at certain centres only. Those grown at all the centres were Beaven's Archer, Webb's Sunrise, Spratt-Archer, Archer-Goldthorpe and No. 25 (a Plumage-Archer selection), Nos. 824 and 825 (Russian Goldthorpe \times Archer Selections) were grown at Long Sutton, Cambridge and Sprowston only. Nos. 832 (derivative of

a Russian Chevallier \times Archer Cross) and 833 (a selection from the original Archer) at Long Sutton and Cambridge only. New Cross was grown at Sprowston only and Standwell at Leegomery only.

The valuations of the barleys and the analyses of the barleys and malts varied substantially at the different stations, as indicated in Table 5, which gives the average results of the control plots all grown from the same pure strain of Plumage-Archer 1924 at the six stations:—

TABLE 5.

AVERAGE OF CONTROL PLOTS.

Centre.	Market Value by Committee.	Moisture per cent. as received.	Malting loss per cent. on dry barley.	Extract lb. 336 lb. dry malt.	Extract lb. per 448 lb. raw barley.
Cambridge	63/7	15.8	10.8	99.2	99.3
Long Sutton	55/-	17.1	10.3	99.0	98.0
Leegomery	55/-	15.2	10.3	97.7	98.8
Newton Abbot	40/-	16.0	10.3	96.0	96.2
Good Easter	39/7	15.1	11.5	98.2	98.4
Sprowston	37/-	16.0	10.9	96.4	96.0

A comparison of the new varieties with the control grown alongside each one is given in Table 6. The results given are the average for each variety at all stations

at which they were grown. The malting loss is expressed as per cent. on dry barley, the extract as lb. per 336 lb. dry malt:—

TABLE 6.

Varieties.			Controls.			
	Valuation.	Malting Loss.	Extract on dry malt.	Valuation.	Malting Loss.	Extract on dry malt.
<i>Average of 6 stations.</i>						
Beaven's Archer	45/8	11.2	98.1	47/10	10.2	97.6
Webb's Sunrise	46/4	11.0	98.1	47/10	10.3	97.4
Spratt-Archer	45/-	10.8	97.9	48/4	10.9	98.0
Archer-Goldthorpe	48/10	10.0	98.5	48/10	10.6	97.9
No. 25	48/6	11.0	97.4	48/10	11.0	97.8
<i>Average of 3 stations.</i>						
No. 825	48/8	11.3	99.9	52/4	10.0	98.3
No. 824	51/-	12.5	99.9	60/-	10.7	96.1
<i>Average of 2 stations.</i>						
No. 832	53/6	12.2	98.9	—	—	—
No. 833	55/-	12.1	99.2	—	—	—
<i>One station only.</i>						
Standwell	55/-	11.9	100.6	55/-	10.8	99.2
Plumage Archer (Winter sown)	65/-	10.0	98.7	—	—	—
New Cross	—	—	96.1	37/-	—	95.7

The superiority (+) or inferiority (—) of the tested varieties over their controls (Plumage Archer) is set out in Table 7, averaged over all the stations at which they were grown :—

All these tested varieties appear to be excellent malting material when grown on suitable soil. In the majority of cases their extracts were higher than that of the Plumage

TABLE 7.

Variety.	Valuation.	Malting Loss.	Extract.	Number of samples.
Beaven's Archer	—2/2	—1·0	+0·5	6
Webb's Sunrise	—1/6	—0·7	+0·7	6
Spratt-Archer	—3/4	—0·1	—0·1	6
Archer-Goldthorpe	=	+0·6	+0·6	6
No. 25	—4d.	=	—0·4	6
No. 824	—9/-	—1·8	+1·2	3
No. 825	—3/8	—1·3	+1·6	3
No. 832	—5/9	—1·7	—0·6	2
No. 833	—4/3	—1·6	—0·4	2
Standwell	=	—1·1	+1·4	1

The average Extracts of the malts from the barleys grown at each centre are set out in the next table :—

TABLE 8.

Locality.	Extract lb. per 336 dry malt.	
	Special Barleys.	Plumage Archer Controls.
Long Sutton	99·1	99·0
Leegomery	98·2	97·7
Sprowston	97·6	96·4
Cambridge	99·5	99·2
Newton Abbot	96·6	96·0
Good Easter	98·2	98·2

When the barleys are arranged in order of the extract given by their malts as compared with their controls the following results are obtained :—

TABLE 9.

Variety.	Extract	
	Comparison with Plumage Archer.	No. of Samples.
825	+ 1·6	3
Standwell	+ 1·4	1
824	+ 1·2	3
Webb's Sunrise	+ 0·7	6
Archer Goldthorpe	+ 0·6	6
Beaven's Archer	+ 0·5	6
New Cross	+ 0·4	1
Spratt-Archer	— 0·1	6
No. 25	— 0·4	6
833	— 0·4	2
832	— 0·6	2

Archer control, though the valuation placed upon them by the Committee of Judges was sometimes markedly lower.

SIX-ROWED BARLEYS.

The National Institute of Agricultural Botany has made trials of certain of the most promising Six-rowed Varieties raised by Dr. Beaven, namely, Nos. F97 and F112. These were grown at Long Sutton and Sprowston against Garton's Squarehead, another six-rowed barley, as control. The barleys grown at Long Sutton were badly damaged in threshing, but those grown at Sprowston came well. In spite of the damage, the brewers' extract yield of the malt was, in all cases, very satisfactory, and the malts, allowing for the damage, were very tender. At Long Sutton a plot was also sown in the autumn with Plumage Archer 1924, alongside the six-rowed barleys, and, eliminating damage, it is noteworthy that the resulting barley provided about the best sample received in 1926, either from the N.I.A.B. or the Institute plots, in which cases the barleys were spring sown.

BARLEYS FROM NATIONAL INSTITUTE OF AGRICULTURAL BOTANY.

TABLE 10.

No.	Variety.	Barley.					Malt.				Market Valuation by Sub Committee. Shillings.		
		Moisture per cent.	1,000 corn weight (grms.) dry.	Nitrogen per cent. on dry.	Malting loss per cent. on dry.	Extract calculated to 448 lb. raw.	Moisture per cent.	Extract per 356 lb. dry.	Colour.	Diastatic power Lintner.	Cold Water extract per cent.	Barley 448 lb. Nov., 1926.	Malt 356 lb. Dec., 1926.
LORD WANDSWORTH AGRICULTURAL COLLEGE, LONG BUTTON.													
150	Beaven's Archer	16.2	34.8	1.421	11.6	97.5	3.50	98.8	4.5	33.2	22.7	50/-	59/-
150c	Control (P.A. 1924)	16.6	35.4	1.368	10.3	99.0	2.60	99.4	5.3	30.7	25.3	55/-	61/-D
151	Webb's Sunrise	17.1	34.7	1.385	11.1	97.5	3.28	99.2	5.2	30.7	23.8	50/-	58/-
151c	Control	17.0	35.1	1.368	11.1	97.3	3.18	98.7	6.0	25.5	24.0	55/-	60/-
152	Spratt-Archer	17.3	33.0	1.374	10.2	97.4	2.58	98.4	5.0	28.8	23.8	48/-	57/-
152c	Control	17.0	34.8	1.306	10.2	98.1	2.74	98.6	5.0	31.6	23.9	55/-	59/-
153	Archer-Goldthorpe	16.8	38.8	1.405	10.8	98.0	2.68	99.2	6.2	27.9	23.0	55/-	62/-
153c	Control	17.4	35.7	1.372	10.3	97.7	3.40	98.9	5.0	31.7	24.0	55/-	62/-
154	No. 25	15.8	39.0	1.481	12.3	97.6	3.28	98.1	4.5	33.3	22.8	55/-	61/-
154c	Control	17.0	36.4	1.362	10.7	97.8	3.00	99.0	5.0	30.7	21.7	55/-	62/-
148	No. 824	16.8	37.2	1.514	12.6	96.0	3.28	99.4	5.2	34.9	23.5	44/-D	57/-D
148c	Control	17.6	36.8	1.368	9.9	98.0	2.84	99.0	4.7	34.4	22.0	55/-	66/-
149	No. 825	16.3	36.8	1.518	10.4	100.3	2.98	100.3	6.0	34.0	22.7	50/-	65/-
149c	Control	17.1	38.2	1.339	10.3	98.1	2.98	99.1	5.0	31.3	22.9	55/-	65/-D
146	No. 832	16.0	34.2	1.338	11.5	97.6	2.96	98.5	4.7	35.8	23.8	48/-D	55/-
147	No. 833	16.2	34.7	1.460	11.3	97.7	2.74	98.6	5.0	31.2	23.2	50/-D	55/-D
LEEGOMERY HOUSE, WELLINGTON.													
156	Beaven's Archer.	15.6	35.0	1.498	11.1	98.6	2.68	98.5	6.0	29.4	24.5	52/-D	55/-D
156c	Control	15.1	36.8	1.402	10.7	99.3	2.94	98.2	6.0	29.6	25.9	55/-D	60/-D
157	Webb's Sunrise	16.0	36.0	1.496	10.6	97.3	2.76	97.2	5.0	29.5	24.6	54/-D	58/-D
157c	Control	15.2	37.2	1.418	10.4	98.4	2.78	97.2	5.0	28.8	24.6	55/-D	57/-D
158	Spratt-Archer	16.1	34.3	1.319	10.9	96.2	2.64	96.5	6.7	28.2	24.2	48/-D	56/-
158c	Control	14.8	37.4	1.454	10.7	99.6	3.13	98.2	5.2	30.2	24.1	55/-D	57/-D
159	Archer-Goldthorpe	14.0	37.5	1.410	10.6	101.3	2.82	98.7	5.2	29.6	23.1	60/-	63/-D
159c	Control	15.2	35.7	1.426	9.2	99.6	2.68	97.0	5.7	28.2	24.1	55/-D	55/-D
160	No. 25	14.8	34.6	1.497	10.4	99.1	2.98	97.4	5.2	30.3	24.3	55/-D	58/-D
160c	Control	15.3	31.9	1.664	11.3	96.4	2.70	96.2	7.0	38.1	24.7	55/-D	55/-D
161	Standwell	15.4	38.5	1.691	11.9	99.3	3.23	100.6	8.0	35.6	25.4	55/-	65/-D
161c	Control	15.4	37.3	1.446	10.8	99.8	3.26	99.2	6.0	26.2	24.5	55/-D	59/-D
NORFOLK AGRICULTURAL STATION, SPROWTON, NORWICH.													
162	Beaven's Archer	15.5	28.0	1.616	12.2	97.2	3.24	98.4	6.0	38.5	25.4	37/-	51/-D
162c	Control	15.3	30.8	1.571	9.6	96.8	3.28	96.1	5.0	37.4	24.9	37/-	51/-
163	Webb's Sunrise	16.2	29.8	1.559	11.3	96.4	3.76	97.3	4.5	40.0	24.5	37/-	51/-
163c	Control	16.0	34.4	1.479	11.5	95.5	2.74	96.4	6.5	35.6	25.0	37/-	51/-
164	Spratt-Archer	16.4	30.1	1.537	11.4	97.1	2.90	96.3	4.5	33.5	25.4	37/-	54/-
164c	Control	15.4	30.9	1.448	11.5	97.6	3.04	97.8	5.2	38.5	24.8	37/-	54/-
165	Archer-Goldthorpe	16.4	32.9	1.568	8.3	98.4	3.08	96.4	5.4	44.4	24.1	37/-	55/-
165c	Control	16.4	31.2	1.520	10.6	95.7	2.72	96.0	4.3	46.0	25.1	37/-	54/-
166	No. 25	15.8	32.6	1.618	9.7	95.9	2.82	95.7	5.3	43.0	24.1	37/-	54/-
166c	Control	16.0	31.5	1.521	11.0	96.2	2.42	96.5	5.7	41.7	25.3	37/-	53/-
167	New Cross	15.8	30.7	1.598	11.3	95.7	2.46	96.1	5.2	40.2	24.8	37/-	54/-
167c	Control	16.4	31.9	1.543	11.4	94.5	2.64	95.7	6.2	45.0	25.4	37/-	52/-
168	No. 824	15.2	29.5	1.511	10.8	99.8	2.94	99.0	5.2	41.6	26.1	37/-	54/-
168c	Control	15.7	30.5	1.460	13.2	93.8	2.66	96.5	6.3	36.8	25.4	37/-	52/-
168a	No. 825	16.4	31.8	1.580	11.9	98.4	2.98	99.3	5.8	44.1	24.6	37/-	57/-
168c	Control	16.0	30.3	1.676	8.4	96.7	3.16	96.5	5.8	46.9	24.7	37/-	53/-
CAMBRIDGE.													
169	Beaven's Archer	16.1	25.5	1.439	9.9	99.7	3.00	98.9	3.7	39.6	22.3	58/-	58/-
169c	Control	15.8	26.8	1.440	9.9	100.2	3.18	99.2	4.2	37.4	22.5	62/-	60/-
170	Webb's Sunrise	15.4	25.1	1.322	11.4	99.6	2.80	99.7	4.0	31.7	22.8	56/-	60/-
170c	Control	16.2	25.8	1.365	9.9	99.8	3.00	99.1	4.7	35.1	23.5	62/-	60/-
171	Spratt-Archer	16.1	24.7	1.253	10.3	99.8	3.04	99.3	4.3	34.7	23.4	58/-	64/-
171c	Control	16.8	25.9	1.326	10.2	98.5	2.96	96.9	4.0	37.0	22.6	65/-	71/-
172	Archer-Goldthorpe	16.7	27.7	1.333	9.3	100.9	3.12	100.2	4.8	31.7	21.8	60/-	67/-
172c	Control	16.0	26.9	1.313	10.8	99.6	3.22	99.7	4.0	39.2	22.8	65/-	65/-
173	No. 25	16.4	28.8	1.387	10.1	99.2	3.44	99.0	4.0	35.7	21.9	64/-	71/-
173c	Control	16.1	27.4	1.357	10.4	100.0	3.12	99.7	5.0	39.2	22.9	65/-	60/-
174	No. 824	14.9	26.6	1.399	12.4	99.0	3.38	99.6	6.7	37.9	23.4	58/-D	61/-D
174c	Control	15.3	27.5	1.412	11.6	98.6	3.38	99.8	5.2	41.4	23.5	65/-	60/-
175	No. 825	17.0	25.7	1.335	11.7	97.8	3.26	100.1	4.3	39.2	24.0	59/-	65/-
175c	Control	17.0	26.8	1.425	10.9	97.7	3.26	99.2	6.0	43.5	23.1	65/-	68/-
176a	No. 832	13.4	25.3	1.459	12.9	98.9	3.52	99.3	6.2	40.4	22.2	59/-D	61/-
176b	No. 833	13.1	24.5	1.377	12.9	99.7	3.24	99.8	5.0	39.2	21.9	60/-D	61/-

TABLE 10 (continued).

No.	Variety.	Barley.					Malt.					Market Valuation by Sub-Committee, Shillings.	
		Moisture per cent.	1,000 corn weight (grms.) dry.	Nitrogen per cent. on dry.	Malting loss per cent. on dry.	Extract calculated to 448 lb. raw.	Moisture per cent.	Extract per 386 lb. dry.	Colour.	Diastatic Power Lintner's.	Cold water Extract per cent.		Barley 448 lb. Nov., 1926.
SEALE-HAYNE AGRICULTURAL COLLEGE, NEWTON ABBOT, DEVON.													
176	Beaven's Archer	16.0	34.3	1.644	11.0	96.0	3.00	96.3	6.7	30.3	24.0	41/-	53/-
176c	Control	16.1	34.1	1.738	10.8	94.8	2.90	94.9	6.3	33.7	25.1	40/-	53/-
177	Webb's Sunrise	16.1	33.7	1.644	10.3	97.2	3.20	96.9	6.7	32.2	23.4	41/-	55/-
177c	Control	15.6	36.9	1.702	8.9	97.7	2.84	95.2	5.7	33.7	23.5	40/-	53/-
178	Spratt-Archer	16.1	33.4	1.562	10.7	96.4	2.76	96.5	4.0	29.0	23.8	41/-	54/-
178c	Control	16.2	33.0	1.746	10.6	96.7	3.54	96.8	5.5	38.3	25.9	40/-	52/-
179	Archer-Goldthorpe	16.2	34.4	1.528	10.5	97.3	3.06	97.3	5.7	37.9	24.3	40/-D	54/-
179c	Control	16.0	34.2	1.737	11.7	95.8	3.64	96.9	5.8	36.2	24.1	40/-	53/-
180	No. 25	15.7	35.2	1.641	11.0	96.0	2.98	96.1	6.2	35.4	23.3	40/-	53/-
180c	Control	15.9	34.1	1.656	10.6	96.2	2.52	96.0	5.3	34.2	24.3	40/-	53/-
EAST ANGLIAN INSTITUTE OF AGRICULTURE, GOOD EASTER, Nf. CHELMSFORD.													
181	Beaven's Archer	14.8	32.5	1.564	11.5	98.1	3.06	97.6	4.0	45.9	21.8	37/-D	54/-
181c	Control	14.9	34.7	1.540	10.8	98.8	2.84	97.6	5.0	45.9	22.8	38/-D	54/-
182	Webb's Sunrise	15.4	36.0	1.504	11.3	98.2	2.72	98.1	4.8	43.0	21.8	38/-D	54/-
182c	Control	15.3	37.2	1.420	11.1	98.4	2.96	98.0	4.3	44.4	22.5	38/-D	55/-
183	Spratt-Archer	14.6	32.8	1.434	11.5	99.3	2.90	98.5	4.0	36.6	23.2	38/-D	57/-
183c	Control	15.1	35.1	1.405	12.6	96.6	3.40	97.7	4.0	41.7	22.7	38/-D	56/-
184	Archer-Goldthorpe	14.9	38.5	1.456	10.3	100.6	3.04	98.8	4.3	42.2	21.2	41/-D	58/-
184c	Control	15.2	37.0	1.415	11.0	99.3	2.78	98.6	5.3	38.5	22.8	41/-D	58/-
185	No. 25	15.0	38.6	1.428	12.7	96.8	2.56	97.9	5.0	40.9	21.7	40/-D	60/-
185c	Control	14.8	36.5	1.406	11.9	99.1	3.20	99.1	4.0	41.1	23.0	41/-D	60/-

TABLE 11.

WINTER BARLEYS.

No.	Variety.	Barley.					Malt.					Market Valuation by Sub- Committee. Shillings.	
		Moisture per cent.	1,000 corn weight (grms.) dry.	Nitrogen per cent. on dry.	Malting loss per cent. on dry.	Extract calcu- lated to 448 lb. raw.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic Power Lintner's	Cold water Extract per cent.	Barley, 448 lb., Nov., 1926.	Malt, 336 lb., Dec., 1926.
Grown at Norwich.													
140	Beaven's F97	12.8	42.4	1.488	11.5	98.5	3.1	95.6	10.3	21.5	25.2	37/-D	—
140C	Control (Squarehead)	13.4	35.9	1.460	8.9	102.4	3.2	97.2	4.3	37.0	19.8	37/-D	—
141	Beaven's F112	12.8	32.5	1.341	10.0	100.7	3.0	95.9	6.6	33.3	22.3	37/-D	—
141C	Control	12.9	35.1	1.403	10.2	100.6	2.8	96.3	5.0	33.3	21.7	37/-D	—
142	Plumage-Archer (Winter Sown)	14.1	37.3	1.341	9.3	104.1	2.8	100.7	5.0	35.0	23.0	60/-D	—
142C	Control	13.7	34.6	1.441	9.3	100.2	2.8	95.8	5.2	37.0	21.5	37/-D	—
Grown at Long Sutton.													
143	Beaven's F97	15.4	40.8	1.504	9.8	93.8	2.8	92.3	7.0	37.0	25.6	36/-	—
143C	Squarehead	16.0	33.6	1.415	12.3	93.0	2.5	94.8	10.5	26.0	22.9	37/-D	—
144	Beaven's F112	16.0	26.1	1.441	12.3	87.3	3.1	90.0	9.5	37.2	27.1	35/-	—
145	Plumage-Archer 1924 (Winter Sown)	16.4	38.9	1.367	10.0	99.0	3.1	98.7	5.5	35.8	22.5	65/-	65/-

THE INSTITUTE OF BREWING RESEARCH SCHEME.

INVESTIGATIONS ON BARLEY.

REPORT ON THE TEN YEARS OF EXPERIMENTS UNDER THE INSTITUTE OF BREWING RESEARCH SCHEME, 1922-1931.

By Sir E. J. Russell, O.B.E., D.Sc., F.R.S., and L. R. Bishop, M.A., Ph.D.

TABLE OF CONTENTS.

	Page
PART I.	
SECTION I.	
INTRODUCTION	288
PREVIOUS INVESTIGATIONS	288
THE PROGRAMME AND METHODS OF INVESTIGATION	289
PROBLEMS STUDIED	290
SECTION II.	
General Consideration of the Laboratory Results.	
1. THE COMPOSITION OF BARLEYS ..	290
(a) The carbohydrate compounds.	
(b) The nitrogen compounds.	
(c) The phosphorus content.	
2. THE CHANGES DURING MALTING ..	294
(a) Nitrogen compounds during malting.	
(b) The enzymes during malting.	
3. THE RELATIONS BETWEEN A BARLEY AND ITS MALT ..	294
(a) The relations between the extract yield and the barley analysis figures.	
(b) The relations of the nitrogen compounds of malt and wort and the barley analysis figures.	
(c) The relations between other malt analysis figures and the barley analysis figures.	
(d) The relations of variety to the barley-malt relations.	
4. THE RELATIONS OF BARLEY TO MALT AND BEER QUALITY ..	300
(a) The relation of barley grade to malt grade and to brewing value.	
(b) Large scale brewings.	
(c) Laboratory brewings.	
5. SUMMARY OF QUANTITATIVE RELATIONS	307
PART II.	
SECTION I.	
THE REQUIREMENTS OF MALTSTERS AND BREWERS	308
SECTION II.	
1.—The Effects of Soil, Season, Manuring and other Factors on the Yield, Composition and Valuation of Barley Grain	310
(1) FACTORS DETERMINING YIELD ..	314
(a) Soil conditions and fertilisers.	
(b) Season.	
(2) FACTORS AFFECTING NITROGEN CONTENT IN GRAIN	317
(a) Soil conditions.	
(b) Season.	
(c) Fertilisers.	
(d) The differences between nitrogenous fertilisers.	

	Page		Page
(3) FACTORS AFFECTING THE 1,000 CORN WEIGHT	324	III.—Effects of Variety on Yield, Composition and Valuation of Barley Grain	326
(a) Soil.		IV.—The Possibility of Controlling Yield and Nitrogen Content ..	333
(b) Season.		Summary of the effects of seasonal conditions on yield and com- position.	
(c) Fertilisers.		V.—The Possibility of Forecasting Yield and Nitrogen Content ..	335
(d) Relation between 1,000 corn weight and nitrogen content of grain.		VI.—Agricultural Recommenda- tions	336
(4) EFFECT OF SOIL CONDITIONS AND MANURING ON VALUATION. ..	325	General Summary: The Progress of the last ten years	339
(a) Soils.		INDEX	343
(b) Fertilisers.			
II.—Effects of Cultivation Treat- ments on Yield and Composition	326	APPENDIX.	
(a) Place of barley in the rotation.		Yields, malting and analytical data for barleys of seasons 1922-31 inclusive (by H. M. Lancaster, H. Lloyd Hind, and F. E. Day).	
(b) Effect of fallow.		<i>Note on Units.</i> —All barley nitrogen contents are given as percentages on dry barley; all thousand corn weights are in grains of dry barley; all yields are as weighed bushels of 56 lb.	
(c) Width of drilling and seeding rates.			
(d) Undersowing.			
(e) Type of cultivation.			
(f) Date of sowing.			
(g) Autumn sowing.			

PART I.

SECTION I.

Introductory Remarks.

The Barley Committee, formed as part of the Institute of Brewing Research Scheme, began its work in 1922 with the following programme of investigations:—

(1) The influence of environmental conditions: soil, season and manuring on the yield and quality of barley.

(2) The possibility of developing new varieties of barley better suited than the present sorts to the maltster, the brewer and the farmer.

(3) The relation of chemical composition of barley to malting and brewing value.

To this programme it has adhered ever since: the three items interlock and are interdependent; the third has necessarily occupied a steadily increasing proportion of the Committee's time and resources.

From time to time a number of papers and interim reports have been published; it is

proposed here to collect and co-ordinate the results already obtained, and also to indicate the problems thereby opened up and the lines on which, in our opinion, the work could usefully be developed.

Previous Investigations.

These lines of enquiry had previously been the subject of a great deal of investigation both here and abroad; in this country much good work had been done by C. O'Sullivan, Horace Brown, E. S. Beaven, J. M. H. Munro, and others. The present researches, as well as the brewing industry in general, owe much to these pioneers of science in brewing. The work prior to 1922 is summarised by H. F. E. Hulton in a report published in this *Journal*¹; we need not, therefore, present a further summary here. This showed a general recognition of the importance of the nitrogen compounds of the barley in determining its malting and brewing properties, but widespread disagreement as to the details of their action.

¹ This *Journal*, 1922, pp. 33-142.

Since the best of the older work was done, many new developments have taken place; biochemistry, physiology and mathematical statistics have grown up and afford new methods for attacking problems of this kind. The Committee's work from the outset was designed to take advantage of these new subjects.

The Programme and Methods of Investigations.

The general method of working adopted by the Committee was to grow barley under the more important of the different soil and climatic conditions in which it is produced in this country, then to examine the grain fully. The examination included:—

(1) Valuation by an expert Committee of the grain and the malt produced therefrom.

(2) Analysis of the grain and the resulting malt by an expert brewer's chemist: H. Lloyd Hind for the first five years, F. E. Day for the remaining period.

(3) Malting tests, large and small scale.

(4) Brewing tests, large and small scale.

(5) Detailed chemical examination of the grain and malt by L. R. Bishop, using modern biochemical methods.

(6) Examination by modern statistical methods of all the experimental figures so as to extract from them all possible information, and in particular to trace any relations that might exist between one set of results and another. These methods yield perfectly unbiased conclusions from the data, and they also give the degree of probability that attaches to the conclusions. At the same time it is no use pretending that they are simple; nevertheless the data are given here, and diagrams and tables are also presented to summarise the results.

The Barley Used.—The necessity for homogeneous material was recognised at the outset, and throughout the experiments the seed used each season at the different centres has all been of the same origin, threshed out from one field.

Plumage-Archer was used for the years 1922 to 1926 and 1929 to 1931, and Spratt-Archer for the years 1927 and 1928; both have been used since, being grown in alternate strips at Rothamsted so as to enable close comparisons

to be made. Plumage and Archer have been used in the variety comparison at Woburn. A wide range of other varieties grown by the National Institute of Agricultural Botany have also been studied.

The centres chosen included some of the best of the barley soils in the country, but the range both of soil and manurial treatment was kept wide, so that the samples finally obtained covered the whole field of the maltsters' requirements and extended into the feeding barleys of too poor a quality for malting. The following pages show that it was necessary to carry the investigation thus far. None of the effects and relations demonstrated here could have been deduced with certainty but for the extreme cases furnished by these low quality samples. It was equally necessary that the low quality samples should be fully as trustworthy in origin and treatment as the better samples.

The Valuation.—This was done by a permanent sub-committee who worked always in the same way and set upon each sample the price which, in their view, it would fetch in the open market. Consistent results were thus obtained which showed certain interesting relationships with the analytical and malting data.

From the outset the sub-committee, consisting of Messrs. R. V. Reid, H. M. Lancaster, O. Wightman and H. D. Cherry-Downes, made it clear that their valuation represented the market price of the barley. No rigid order of merit for brewing is possible because the barley best suited for one purpose would not be best for another. The sub-committee's valuation has the advantage of representing by single figures those qualities of barley which are revealed by inspection and appeal to buyers in general; we have accordingly not hesitated to apply to them the same statistical tests as to the analytical figures.

The Malting.—The Committee's programme necessitated a far larger number of maltings than could possibly have been made on the commercial scale; a small scale method was therefore necessary. The stocking method devised by E. S. Beaven¹, and worked by H. M. Lancaster, seemed promising; a number of comparisons with large

¹ This *Journ.*, 1902, 542

scale maltings were accordingly made in order to test it thoroughly.

At a number of the experimental centres sufficient of the barley was grown to give 20 quarter samples, and as many of these as possible were malted in the ordinary way by a group of maltsters who generously undertook this part of the work, and to whom the Committee wishes to tender its warmest thanks : Messrs. Hugh Baird & Sons, Gilstrap Earp & Co., James D. Taylor & Sons, William Younger & Co. At the same time stocking maltings of the same samples were made by H. M. Lancaster at Messrs. Fuller, Smith and Turner's Maltings. All the malts were then valued and analysed.

The Stocking method was found substantially to represent the results of the large scale malting. When they were made together, analyses of the bulk and of the stocking samples gave almost identical results for extract and permanently soluble nitrogen, and agreed closely for colour, diastatic power, cold water extract and malting loss ; the stocking malt yielded somewhat more cold water extract, and contained somewhat less diastase, than the bulk samples, presumably because there is less aeration in the stocking than in the bulk.

The extent of agreement is given in Messrs. H. Lloyd Hind and H. M. Lancaster's paper.¹

Having satisfied themselves of the validity of the Stocking method, the Committee used it in all the subsequent work and discontinued the large scale tests.

The Brewing Tests.—Some of the large scale malts were brewed by Messrs. Wm. Younger & Co., Georges & Co., The Northampton Brewery Co., and Truman, Hanbury, Buxton & Co., and the beers were examined by an expert sub-committee. This process, however, was found to be very laborious, and search was made for a small scale method that would give the desired information more conveniently. In 1928 F. E. Day devised² a small scale brewing method which he has since improved. This requires only the small samples of malt obtained in the stocking method, and yet gives quite a satisfactory comparison of the brewing qualities of the malts, including the

flavour, brilliancy, stability and head retention of the resulting beers.

These small scale methods require only about 2 lb. of barley for the malting and brewing and for the complete analyses of both barley and malt ; they have enabled the Committee to examine in detail large numbers of barleys grown under a wide range of conditions and differing therefore very widely in their chemical composition. The final test, of course, must be the brewery experience, but the small scale experiment allows all the preliminary sorting out to be done quickly, economically and under strictly comparable conditions. It therefore allows a selection to be made of the points that can justifiably and with promise of success be tested on the large scale.

The Problems Studied.

By the aid of these methods, the following problems have been studied :—

(1) The relation between the chemical composition of the barley and the extract yield of the malt and the composition of the wort obtainable therefrom.

(2) The relation between the composition of the extract from the malt and the properties of the resulting beer.

(3) The relation between valuation, *i.e.*, market price, of the barley and the yield and composition of the resulting malt and beer.

(4) The ways in which the composition of barley can be altered so as to produce grain of desired characteristics.

Up to the present the investigations have been confined chiefly to properties that could be measured, such as extract obtainable, and it has not yet been possible to study to any great extent properties associated with quality of beer. We are not yet in a position to give a full definition of what constitutes brewing quality or to say how, if at all, it can be measured. Nevertheless, some of the striking regularities brought out by the Committee's investigations indicate that, before long, answers to these questions may be forthcoming.

SECTION II.

General Consideration of the Laboratory Results.

I.—THE COMPOSITION OF BARLEY.

The constituents of barley may be divided into four groups :—

¹ This *Journal*, 1932, 290.

² *Ibid.*, 1928, 570 ; 1931, 202 ; 1932, 16 ; 1932, 303.

(1) The starch, which, as the main source of the sugars, alcohol and dextrins, is the most necessary to the brewer; there are also small quantities of sugars as such. These together amount to about 65 per cent. of the grain.

(2) The nitrogen compounds which are important in several ways although amounting only to about 12 per cent. of the grain. The greater the total quantity of proteins the more the starch content is reduced and some of the protein derivatives exercise a potent influence on yeast nutrition and on the flavour and other properties of beer.

(3) The cellulose and other non-nitrogenous compounds associated with the cell walls amounting to about 10 per cent. These are not dissolved in the mashing process: they form the fabric so to speak of the grain while (1) and (2) may be regarded as the contents.

(4) Ash constituents, fats and other compounds present in small amounts.

(a) Carbohydrate Compounds in Barley.

If the starch could easily be removed and estimated, the work on barley would be greatly simplified. It is, however, so nearly related to some of the other compounds, the hemicelluloses, that no sharp separation has yet been found possible by any simple laboratory method. Laboratory methods either over-estimate or under-estimate the starch: repeated attempts in the past 40 years have as yet failed to give accurate values. This problem was being studied until quite recently by Prof. A. R. Ling at Birmingham and the Committee felt they could not do better than leave the field to him¹.

The cellulose of barley grain has not been studied. The hemicelluloses, however, have been investigated by one of Prof. A. R. Ling's colleagues, I. A. Preece², at Birmingham, who found in the spent grains of malt four separate members of this group; three of them are very similar to the hemicelluloses in wood and other plant products.

Approaching the subject in a different way, Bishop³ finds evidence that the amounts of the various carbohydrates in the barley grain are not independent of each other, but are closely related in quantity to one another, the exact proportions depending on the total

amount of carbohydrate present (see p. 307). It will be seen below that the nitrogen compounds show similar relations: some consequences of this will be discussed later (see p. 297).

(b) The Nitrogen Compounds.

The nitrogen compounds, which were already known to be of great importance, have occupied the major portion of the work of the Committee. The investigation has proceeded on three lines:

(1) What are the chief nitrogen compounds of barley?

(2) What is the relation between the nitrogen compounds and the starch? Or, alternatively, as proved simpler and more important in practice, what is the relation between the nitrogen compounds and the extract available?

(3) What are the effects of the various nitrogen compounds on the brewing processes and products?

The chief nitrogen compounds of barley.—

The pioneering work of Osborne⁴ showed that barley contains four proteins, an albumin, a globulin, a glutelin and hordein, which is soluble in alcohol; also simple amino acids and other nitrogen compounds intermediate in complexity between these and the proteins. The mixture is very complex and its constituents are separated only with difficulty.

A number of the earlier workers² endeavoured to separate the hordein by extraction with 70 per cent. alcohol, and it was widely supposed that the amount of hordein so obtained gave a good estimate of the quality of barley for malting. Bishop,³ however, showed that direct use of alcohol does not give a clean extraction of hordein: it removes some of the salt-soluble material and, unless hot, it fails to extract all the hordein. This observation explains the result recorded by Munro and Beaven,⁴ that the directly extracted alcohol-soluble nitrogen rises to a maximum during the development of the barley grain and then falls off. Bishop, on the other hand, shows that the

¹ *J. Amer. Chem. Soc.*, 1895, 17, 539.

² Among them J. M. H. Munro and E. S. Beaven, *J. Roy. Agric. Soc.*, 1900, 61, 185. E. S. Beaven, *this Journ.*, 1902, 542. A. J. Murphy, *this Journ.*, 1903, 557. E. Prior, *Zeit. ges. Brauw.*, 1906, 29, 613.

³ *This Journ.*, 1928, 101.

⁴ *Ibid.*, 1902, 542.

¹ *This Journ.*, 1931, 216; 1931, 595.

² *Ibid.*, 1931, 409.

³ *Ibid.*, 1933.

PERCENTAGES OF NITROGEN IN SEPARATE PROTEINS OF BARLEY.

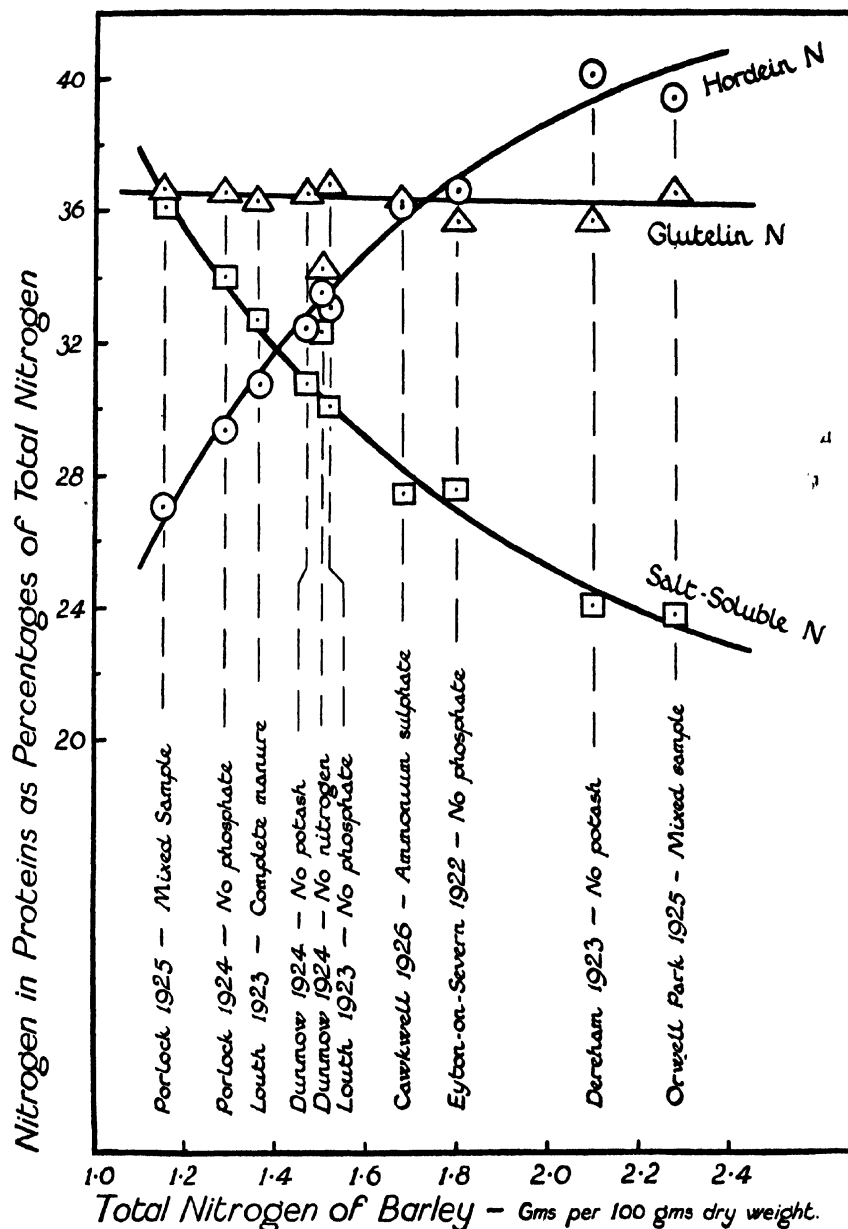


Diagram 1. The forms in which the nitrogen occurs in Plumage-Archer grain. The percentage of the nitrogen present in the different forms is plotted against the total nitrogen, and the diagram shows that the values all fall on smooth curves, no matter where the samples come from or what the manural treatment has been. In other words the pattern remains constant.

proportion of hordein steadily increases while the salt-soluble nitrogen compounds steadily decrease during the development¹: at first the gain in the hordein suffices to increase the amount of direct alcohol extract of Munro and Bevan, but later the fall in salt-soluble compounds is so large as to bring it down.

Bishop finds that the amounts of the various proteins in the fully mature grain are, for a given variety, closely related to the total quantity of nitrogen. Starting with the same batch of seed, but varying the conditions of growth, the percentage of nitrogen in the resulting barleys varied from 1.2 to 2.4, corresponding to variations in total protein content from about 7.2 per cent. to 14.4 per cent. The proportions between the proteins varied in a definite manner so that, for any given total nitrogen content, it was possible to state the percentages of the individual proteins. In Plumage-Archer of nitrogen percentage about 1.4 the hordein, glutelin and salt-soluble nitrogen compounds are all present in approximately equal amounts. As, however, the nitrogen percentage increases the hordein increases more than proportionately to the nitrogen, the glutelin increases proportionately and the salt-soluble protein increases much less. At a nitrogen percentage of 2.4 the proportions of the three groups of compounds are definite but entirely different from those in the 1.4 per cent. barleys. (Diagram 1). Other varieties show similar regularities, and the regularities are particularly clearly marked when the results are calculated per 1,000 corns.¹

In immature grain the salt-soluble nitrogen is higher, and the glutelin and hordein nitrogen lower, than in the mature grain. This result, which is confirmed by G. Hoffman Bang,² affords a possible method of estimating the degree of maturation.

Six-rowed varieties differ from two-rowed in that the former usually contain less alcohol-soluble protein. This was shown by Beaven³ and has been confirmed by Bishop⁴ and Ivanoff.⁵

These regularities are so important that it was necessary to establish them beyond dispute. A large number of analyses have accordingly been made, using barleys of high, medium and low nitrogen content, and in every instance the results have been entirely in accordance with the rule. Independent confirmation has since been obtained by Hoffman-Bang at the Tuborg Laboratories, Copenhagen,¹ and the methods have been employed by a number of continental workers. Ehrich and Kneip's² results with the methods show the same relationship of hordein and of salt-soluble nitrogen to total nitrogen as Bishop obtained, though they did not deal with this question; their conclusion was that steely barley contains more nitrogen and a higher proportion of hordein than mealy barley, which had already been shown by Munro and Beaven in 1900.³ There is no basis for Ehrich and Kneip's implication that steely barleys are exceptional in their hordein contents.

The important result follows from Bishop's figures that the proportions of the different nitrogen compounds for any one variety depend only on the percentage of nitrogen present, and not at all on the way the nitrogen got there, whether as the result of soil conditions, seasonal factors or manuring. A good barley soil heavily manured with sulphate of ammonia can give grain indistinguishable in its nitrogen compounds from barley grown on a fen soil. The curves expressing the relation between nitrogen content and the proportion of nitrogen compounds when once determined for a given variety of barley, appear to hold true for all samples of that variety.

While, therefore, variations in soil, climate and manuring can cause wide difference in "quality," they do not upset either the quantitative relations of the individual proteins to the total nitrogen or, as far as present methods show, alter the composition of the individual proteins. It does not necessarily follow, however, that the wide differences in "quality" are unrelated to the proteins, for there still exists the possibility of important differences in the physical states and behaviour of the proteins resulting from different external conditions, as well as

¹ This *Journ.*, 1930, 336.

² *Ibid.*, 1931, 72.

³ *Ibid.*, 1902, 542.

⁴ *Ibid.*, 1928, 101.

⁵ N. N. Ivanoff, *Biochem. Zeit.*, 1932, 250, 430.

¹ This *Journ.*, 1931, 72.

² *Zeit. ges. Brauw.*, 1931, 54, 1, 9.

³ *Journ. Roy. Agric. Soc.*, 1900, 61, 185.

the possibility of subtle differences in chemical composition undetectable by present-day analysis.

(c) *The Phosphorus Content of Barley.*

The phosphorus in barley grain exists chiefly as phytin, which is the phosphoric ester of the ring sugar inositol. This has not been studied in detail, but the phosphorus content of many of the experimental barleys has been determined by E. M. Crowther.¹ The amount varies only slightly; it is about 1 per cent. (as P_2O_5) of the dried grain; there are no such large variations as are shown by the nitrogen. Large changes in soil and season made only slight differences, while the effect of manuring was hardly perceptible; nitrogenous manuring by resulting in increased yield caused a slight depression, but phosphatic and potassic manures were almost without effect.

Despite the undoubted value of phosphorus in brewing, normal samples of English barley are not likely to show much variation in the quantity they contain, and variations in quality are therefore not to be sought in this direction.

2. THE CHANGES IN THE PROTEINS DURING MALTING.

(a) *The Nitrogen Compounds.*—Osborne and Campbell² showed that malt contains four proteins, each similar to the corresponding one in barley, but they thought that the alcohol-soluble proteins of barley and of malt were not identical; they suggested also that the salt-soluble proteins of the two were different. A strong case, however, for the identity of the alcohol-soluble hordein of barley with the "bylin" of malt, has been made by recent workers, Lüers,³ Kraft⁴ and Bishop.⁵ Kraft showed that hordein disappears during malting, and Bishop⁶ has confirmed the breakdown of the two insoluble proteins, hordein and glutelin, during the period of active change (2-6 days on the floor).

With two-rowed barleys, changes in the length of steep, in the flooring period and

in the quantity of sprinkling water, appeared to have very little effect on the relative proportions of the different nitrogen compounds in the malt.¹ This Bishop explains as the result of dynamic equilibrium between breakdown in the endosperm and re-synthesis in the germ. R. H. Hopkins² has independently shown by titration methods that the amino-acid and the phosphate buffering increase rapidly between the second and sixth days on the floor, and he confirms the apparent cessation of change in the nitrogen compounds after this stage, both on the floor and on the kiln, even under forcing conditions; this latter observation had already been made by H. T. Brown³. Stadler⁴, using Bishop's methods, demonstrated further that a sample of barley floor at a high temperature (79° F.) gave much the same proportions of the different nitrogen compounds in the malt as another sample of the same barley floor at a lower temperature (66° F.). Confirmation and development of this work are highly desirable.

(b) *The Diastase.*—As malting proceeds the diastase increases proportionately with the salt-soluble compounds. Bishop has shown that each increase of 10° F. in the maximum temperature decreases the final D.P. by 2° Lintner. For every degree the flooring temperature is raised, the final D.P. is decreased half a degree Lintner. Lloyd Hind, Threadgold and Arnold have improved the conditions for accurate estimation of the enzyme⁵ by using an acetate buffer at p_H 4.6 to stabilise the hydrogen ion concentration during the starch conversion.

3. THE RELATIONS BETWEEN A BARLEY AND ITS MALT.

(a) *The Relation between the Extract Yield and the Barley Analysis Figures.*

The Committee have devoted considerable attention to the elucidation of the conditions determining the extract yield, perhaps the most important of all the measurable properties of malt.

The stocking method has been shown to give practically the same figure as a bulk

¹ This *Journ.*, 1930, 349.

² *J. Amer. Chem. Soc.*, 1896, 18, 542.

³ *Biochem. Zeit.*, 1919, 96, 117; *ibid.*, 1922, 133, 603.

⁴ *Zeit. ges. Brauw.*, 1910, 33, 193 and 205.

⁵ This *Journ.*, 1929, 316.

⁶ *Ibid.*, 1929, 323.

¹ This *Journ.*, 1929, 323.

² *Ibid.*, 1929, 402.

³ *Ibid.*, 1909, 169.

⁴ *Woch. Brau.*, 1929, 46, 479.

⁵ This *Journ.*, 1926, 26.

TABLE 1.
COMPARISON OF TWO DIFFERENT MALTSTERS' RESULTS WITH THE SAME BARLEYS.

Stocking Maltings.

Sample No.	Extract, lb.		D.P.		C.W.E.		Colour.		P.S.N.	
	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.
401	99.7	98.5	55	35.5	22.7	19.2	2.5	4.7		
402	99.8	98.6	55.5	38	22.5	18.6	2.8	3.8		
403	99.4	99.2	52	40.5	21.2	19.1	3.0	4.3		
404	99.3	99.4	56.5	36.5	21.4	18.6	2.5	4.0		
405	100.2	100.3	48.5	40.5	20.0	19.0	3.0	6.7		
406	101.8	101.8	44.5	37	22.1	19.2	2.8	6.2		
111	100.3	100.2	52	50	20.9	19.7	2.5	3.5	0.55	0.56
113	101.1	100.8	50	48.5	22.8	20.7	2.7	3.2		
114	101.8	101.6	49	51	23.0	21.3	3.2	3.7	0.55	0.52
117	99.6	100.1	42.5	41.5	19.6	18.8	3.0	3.5	0.54	0.54
118	100.4	100.4	34	32.5	18.4	17.5	3.3	3.5	0.53	0.48
119	100.6	100.6	39	37.5	19.1	17.8	4.2	4.0	0.56	0.48
120	100.0	100.6	60	56	21.6	20.9	5.7	6.0	0.70	0.63
Average	100.3	100.2	49.1	41.9	21.2	19.3	3.2	4.4	0.57	0.54

I. and II. refer to the two maltsters.

TABLE 2.
MALTING CONDITIONS FOR BARLEYS 111-120.

					Steep.		Floor.		Kiln.	
					Time.	Temp.	Time.	Temp.	Time.	Max. Temp.
Maltster I.	..	..	..	..	60 h.	56° F.	7 days.	62° F.	96 h.	180° F. for 8 h.
Maltster II.	..	..	..	..	74 h.	50° F.	9 days.	58° F.	72 h.	178° F. for 36 h.

malting when conditions are similar¹, and varying conditions in two different maltings were found to produce no significant differences in the yield of extract, although the other analysis figures are affected. This is shown in Table 1, above. The extract is influenced by the regularity of germination and germinative capacity, but the most important factors affecting it are the nitrogen content and the variety, with a smaller effect from the 1,000 corn weight. During the first seven seasons no fewer than 666 samples were analysed—mainly Plumage-Archer and Spratt-Archer—and the close relation between the three factors, extract,

nitrogen content and 1,000 corn weight, was always clearly shown. The results for 1928 are set out in Diagram 2, where the circles show the relation between nitrogen content and extract. The results show clearly that high extract is associated with low nitrogen and *vice versa*, thus confirming, as do all sets of the Institute results, the relation first shown in this country by E. S. Beaven.¹ If, however, the barleys within the dotted rectangle (Diagram 2) are considered, the relation is not at all clear. These constitute the range of good malting barleys, and it is because previous investigators restricted their enquiries to

¹ This *Journ.*, 1932, 290.

¹ This *Journ.*, 1902, 542.

so narrow a range that the relation between nitrogen and extract has been so long under discussion and doubt.¹

The squares at the top of the diagram show the relation between nitrogen content

¹ This conflict of opinion is dealt with by Hulton in his summary of the 1921 position of knowledge about barley and malting. (*This Journ.*, 1922, 33).

He states, "In the course of an examination of the published work of 25 different workers dealing with the relation between the nitrogen content of barley and the quantity of extract obtainable from the malt, it appears that 13 (or 50 per cent.) pronounce unhesitatingly in favour of the view that more nitrogen in the barley means less extract in the malt; nine of them (or 36 per cent.) are doubtful that such a definite relationship holds; while the remaining three (14 per cent.) pronounce positively that no such relationship exists. The balance of opinion is thus clearly on the whole in favour of the view that 'extract' varies inversely as the nitrogen content of the original barley."

Other reasons for previous failure to establish the relation beyond doubt and in a quantitative fashion are the small numbers of samples considered, the confusion due to differences in varieties, to defective germination, to neglect of the importance of 1,000 corn weight, and finally, to failure to use statistical methods.

and thousand corn weight on the one hand, and the extract of the malt on the other. The agreement is so close that discrepancies can usually be attributed to the small errors inevitable in the sampling and analysis. The conclusion that the extract decreases as the nitrogen content rises and increases as the thousand corn weight increases is established by statistical examination of the whole of the data assembled during the Committee's experiments.

It is expressed by L. R. Bishop in his prediction formula :

$$E = 108.3 - 10.5 \times N + 0.20 \times G \\ \dots \pm 1.4 \text{ (68\%)*} \dots^1$$

where E = extract in brewers' pounds per quarter of dry malt determined by the Institute of Brewing standard method.

* The standard error. This figure (in this case ± 1.4) implies that 68 per cent. of a large number of predictions will be within the figure given. It is, therefore, a measure of the accuracy of the equation.

¹ *This Journ.*, 1933.

RELATION OF NITROGEN CONTENT AND THOUSAND CORN WEIGHT WITH EXTRACT.

1928 INSTITUTE BARLEYS (SPRATT-ARCHER).

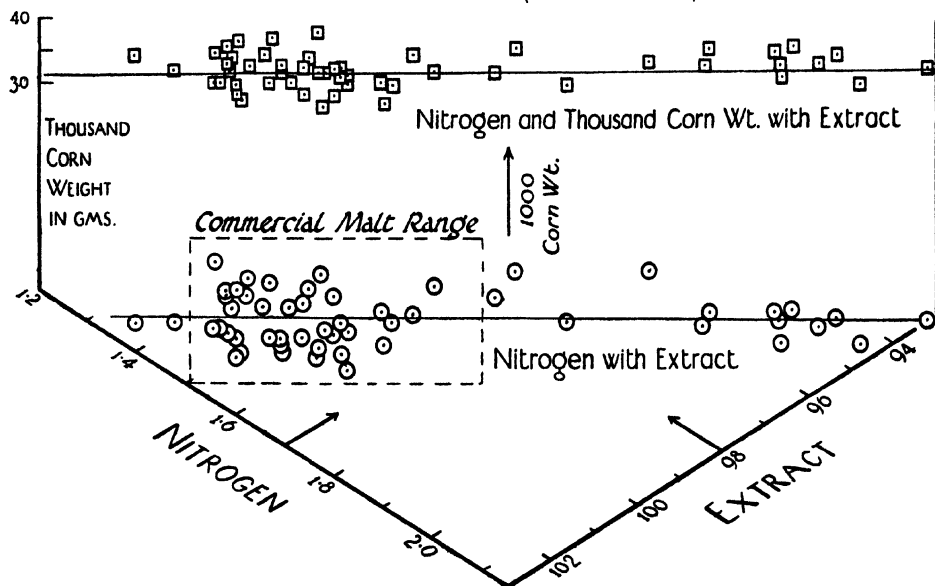


Diagram 2. This diagram shows that the quantity of brewers' extract obtainable from any particular variety of barley under standard conditions is regulated almost entirely by the nitrogen content and the 1,000 corn weight of the grain. The results are plotted in such a way that, if these two were the only factors concerned, all the points about the upper line should fall on the line. Almost all of them do so, within the errors of the determination, whether they are good malting samples or bad.

Nitrogen content alone is taken into account in the lower line, and here the agreement is not quite so good, but it is sufficiently close to show that nitrogen content is by far the more important factor.

N = nitrogen percentage in dry barley.

G = weight of 1,000 dry corns in grams.

This is the equation for Plumage-Archer, the most commonly grown barley in England, but with slight modification it can be adapted to any variety¹. It has been independently tested by W. J. Mitchell² and others and found to hold generally true.

One reason for the connection between the high nitrogen and low extract is fairly clear: every 0.1 per cent. of nitrogen represents about 0.6 per cent. of nitrogenous substances and therefore correspondingly reduces the amount of carbohydrate material that can be present. The factor is however nearly twice as large as would be expected on this hypothesis. The connection with 1,000 corn weight is also clear: small grains have correspondingly more insoluble husk and structure material and less starch than large ones. Instead of the 1,000 corn factor, G, it would be more direct to use a factor expressing the amount of insoluble carbohydrate corresponding to that in spent grains, and this is now being done by Bishop in a new equation shortly to be published. The resulting equation is of much wider applicability as it eliminates the need for a knowledge of the variety.

When the variety is known the extract can be predicted by substituting the appropriate constant in the prediction equation. The following is a list of some of the constants calculated from the Institute results:—Standwell and Golden Pleasant, 110; Spratt-Archer, 108.6; Plumage-Archer, 108.3; Archer, Sunrise, Golden Archer, 108; Californian Atlas and Tennessee Winter, 101.5. These are for substitution for A in the equation:

$$E = A - 10.5 N + 0.2 G.$$

The prediction formula is not only useful in showing the extract that a barley can yield: it serves also as a check on the efficiency of the malting process. The difference between the observed and predicted extract shows whether the results are above or below a good average performance. We have received many proofs of the practical value of the prediction formula to maltsters

and to maltster-brewers. We would again emphasise the fact that the formula could not have been established without both the very high quality and the very low quality barleys produced in these experiments.

(b) *The Relations between the nitrogen compounds of Malt and Wort, and the Barley analysis figures.*

In 57 barleys and their malts of the season 1922¹ the nitrogen in the dry malt was practically the same as that in the dry barley, the relation being as follows:—

N. of malt = N. of barley— 0.025 ± 0.001 .
Later determinations confirm this result.

(N. = per cent. of nitrogen in the dry matter).

The nitrogen compounds of the worts are in turn closely related to the total nitrogen content of the malt. H.T. Brown² showed that the permanently soluble nitrogen finally obtained in the wort is approximately 38 per cent. of the total nitrogen of the barley. The Committee's results³ show that the actual percentage in any given case depends on the extent of modification of the malt. The average has been for two-rowed barleys 35 per cent., and for six-rowed barleys 27 per cent. These figures assume an approximately constant malting loss. As the latter increases the permanently soluble nitrogen, expressed as a percentage of the nitrogen content of the barley, increases. Amino, amide and peptide nitrogen in the boiled wort increase regularly with increasing total nitrogen of the barley, though the increases in amide and amino nitrogen are only small. These regularities are confirmed by recent estimations, still in progress, of the "simple amino nitrogen" in the wort.

This simple amino nitrogen in the wort, however, accounts for only a small part of the difference between worts from low nitrogen and from high nitrogen barleys, or from two-rowed and six-rowed barleys: most of the difference is represented by nitrogen in the peptide form which includes the larger part of the nitrogen in the more complex compounds.

It is important to realise how small all these changes are when compared with the total material in the barley grain. The relations between the nitrogen content

¹ This *Journ.*, 1931, 463.

² *Ibid.*, 1932, 241.

¹ This *Journ.*, 1924, 969.

² *Ibid.*, 1909, 169.

³ *Ibid.*, 1931, 345.

of the barley and the resultant products after malting and mashing are shown in the summary diagram (3) below. The figures are mostly derived from Institute experiments. It is evident at once that even between the extreme case of barleys of 1.0 per cent. nitrogen and 2.0 per cent. nitrogen, the differences are small.

(c) *The relations between other Malt analysis figures and the Barley analysis figures.*

The other values usual in malt analysis—the diastatic capacity, the solids extracted by cold water, the malting loss and the colour—are all changed as is well known by changes in the malting conditions (see Table I, p. 295). Experiments now in progress indicate that

RESULTANT PRODUCTS FROM BARLEYS OF 1.0—2.0 % NITROGEN AFTER
THE MASHING STAGE.

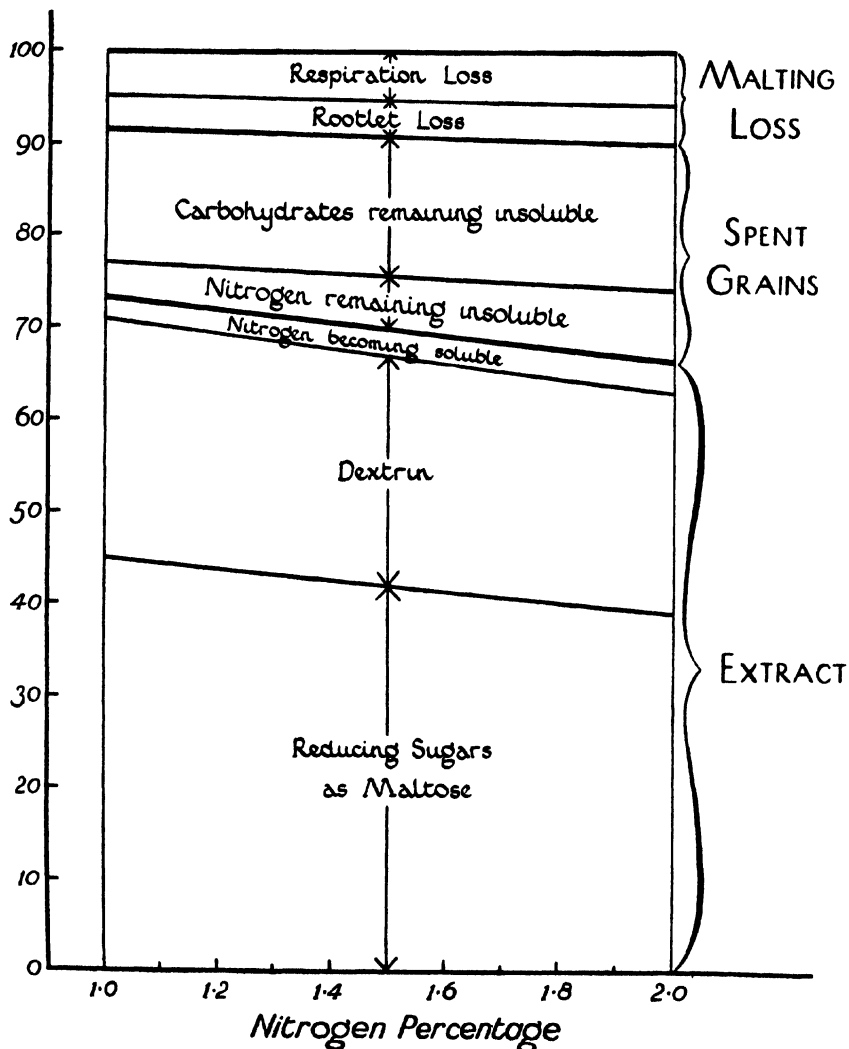


Diagram 3. This shows the quantities of various products obtained from two-rowed barleys of various nitrogen contents. As the nitrogen content of the barley increases, so the quantities of reducing sugar and dextrin in the extract decrease; on the other hand, the nitrogen compounds, especially the insoluble ones, increase as also do the insoluble carbohydrates, the respiration loss and the rootlet loss.

RELATION BETWEEN NITROGEN CONTENT AND EXTRACT FOR DIFFERENT VARIETIES.

ALL EXTRACTS CORRECTED TO THAT FOR 38 GMS. 1,000 CORN WEIGHT.

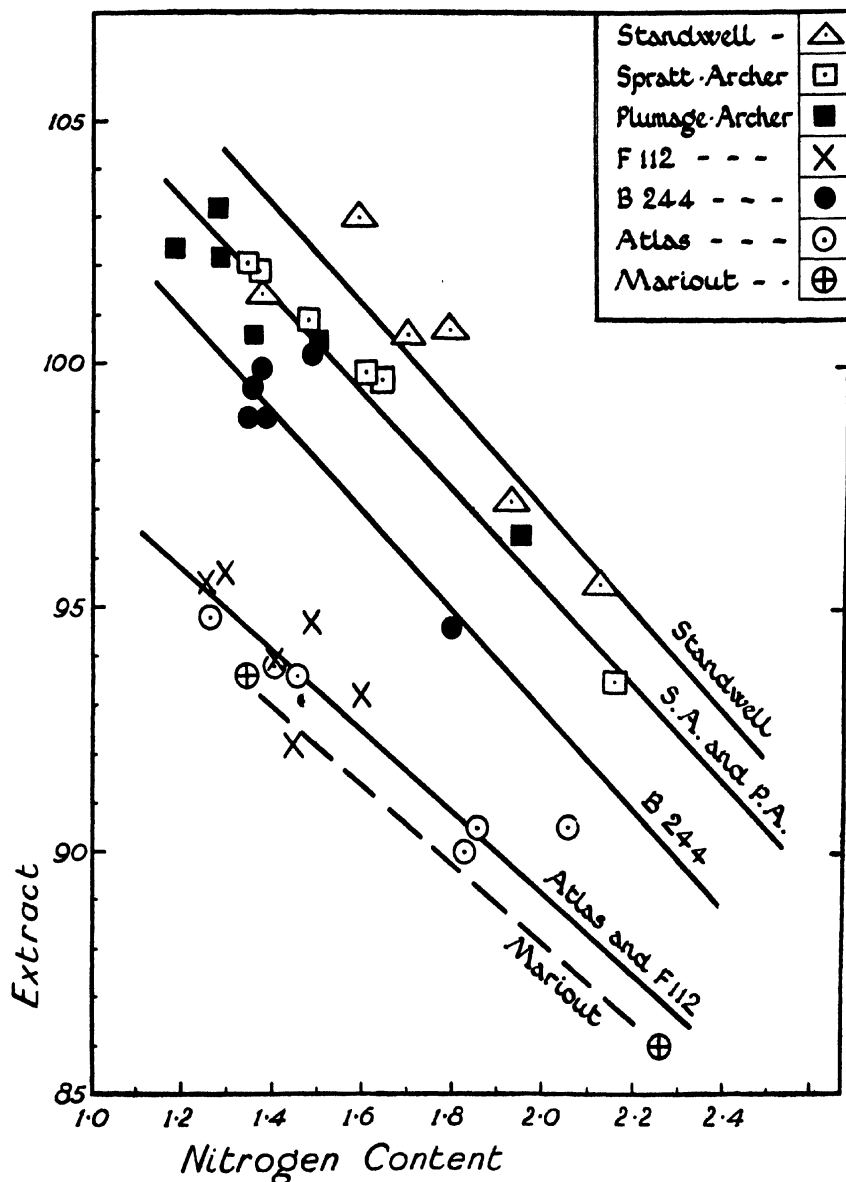


Diagram 4. The quantities of extract yielded by barleys of different varieties are seen to decrease regularly as the nitrogen content of the grain increases. The points fall very close to straight lines which are almost parallel. The results show that the difference between any two varieties in extract is the same whatever the nitrogen content of the grain.

the relative potentialities of different barleys are predictable from nitrogen content, thousand corn weight, and a factor still to be defined; it is hoped that before long the effect of any given change in malting conditions can be calculated, so that any necessary adjustments in these conditions can be decided beforehand. The maltster will then know before he malts a barley approximately what the malt analysis will be.

(d) *The influence of variety on the Barley malt relations.*

All through the work evidence has accumulated that the different varieties of barley behave very much alike on malting but with definite small differences. These arise from the circumstance that varietal differences in nitrogen content, yield, carbohydrate composition and thousand corn weight tend to persist in the grain in spite of differences in growing conditions: one variety tending to be regularly above or below another. If for instance Plumage-Archer and Golden Pheasant be grown side by side under similar conditions the latter nearly always contains about 0.16 per cent. more nitrogen (see page 332). In consequence of the persistence of varietal differences in carbohydrate composition there are corresponding regular differences in yield of extract from the malts of different varieties of barley of equal nitrogen content. Thus a change of variety will change the extract for two reasons: the new variety consistently gives a higher or lower proportion of total carbohydrate to nitrogen, and its carbohydrate differs in composition.

The regularity of the varietal difference in extract is shown in Diagram 4 from the Institute results over a very wide range of nitrogen content and variety. In this diagram the extract (with a small correction to constant thousand corn weight) is plotted against nitrogen content for a wide range of varieties. It will be seen that the nitrogen content produces parallel effects in the different varieties. Similarly it has been shown¹ under normal malting conditions that two-rowed barleys regularly give about 35 per cent. of their nitrogen in a permanently soluble form in the malt, while most six-rowed barleys give about 27 per cent.

Certain general differences have emerged between two-rowed and six-rowed varieties. The two-rowed varieties in general differ but little among themselves in carbohydrate composition, and hence give similar extracts for a given nitrogen content. The six-rowed barleys, on the other hand, show a wider range in carbohydrate composition, and therefore also in extract. For a given nitrogen content, the six-rowed varieties from California give low extracts; those from India¹ give higher extracts which, however, are still below the extracts obtained from most two-rowed varieties; some Canadian six-rowed varieties give higher extracts still.

The differences between varieties are thus of a regular quantitative nature, and the way is opened for the breeding of varieties which can be relied on to give malts of the composition found to be most desirable. For instance, Standwell would give high extract combined with high soluble nitrogen should this prove desirable, although agriculturally this variety has serious defects. The present results and methods should thus prove of assistance to the barley breeder.

(4) *THE RELATION OF BARLEY TO MALT AND BEER QUALITY.*

This is the most difficult, the least studied and at the same time the most important part of the work. At the outset one is confronted with the difficulty of defining and measuring "quality" in beer. The flavour as affected by the barley is only one factor: the brightness and stability of the beer are important as also are problems of yeast nutrition and activity. Nevertheless it is possible to learn something by the purely empirical method of tasting and valuation.

(a) *The relation of Barley grade to Malt grade and to brewing value.*

The Valuation Sub-Committee has made it clear throughout its whole activities that its figures are not meant to show the true value of the barley to the brewer, but only the price that it would fetch in the open market. For purposes of comparison between different years the prices have been converted to grades. The grade prices in the different years are given in Table 3 and the average analytical data of the barleys and malts in the different grades are given in Table 4.

¹ *This Journ.*, 1909, 169; 1931, 345.

¹ H. Lloyd Hind. *This Journ.*, 1931, 463.

TABLE 3.

SCHEDULE OF GRADE PRICES OF ENGLISH BARLEYS.*

In Shillings per quarter of 448 lb. f.o.r. farmers' stations, at date of valuation.

Type.	Grade.	1922.	1923.	1924.	1925.	1926.	1927.	1928.	1929.	1930.	1931.
Pale Ale ..	I.	55-60	55-60	95-120	80-90	80-90	70-80	68-75	57-62	55-60	55-60
	II.	50-54	50-54	85-94	70-79	69-79	60-69	59-67	52-56	50-54	50-54
	III.	46-49	46-49	75-84	60-69	58-68	55-59	53-58	46-51	45-49	45-49
Mild Ale ..	IV.	43-45	43-45	65-74	50-59	50-57	50-54	49-52	41-45	40-44	39-44
	V.	40-42	40-42	55-64	43-49	43-49	45-49	42-48	36-40	33-39	34-38
	VI.	35-39	35-39	45-54	35-42	35-42	40-44	36-41	28-35	26-32	30-33
Grinding ..	VII.	34	34	44	34	34	39	35	27	25	29

NOTE.—All prices below those mentioned in Grade 7 are also Feeding and Grinding.

*Data kindly furnished by Messrs. Hugh Baird & Sons.

TABLE 4.

ANALYTICAL DATA FOR THE DIFFERENT GRADES OF BARLEY AND MALT.

Means of the centre averages for all samples malted, 1922-1931.

Grade.	No. of Centre Averages.	Barley.		Malt.	
		N %	1,000 corn wt. gms.	Extract lb. per qr.	Diastatic Power.
I.	2	1.558	42.6	100.0	35.1
II.	7	1.416	40.6	100.6	29.9
III.	11	1.486	40.2	99.7	33.6
IV.	13	1.491	39.0	98.6	28.4
V.	24	1.554	38.5	98.5	39.6
VI.	25	1.686	38.1	97.6	44.0
VII.	8	1.592	37.8	97.8	42.7

These grades can be said to represent the value of the barley apart from fluctuating market conditions. The Institute set affords exceptionally good material for determining these grades and making a comparison with the analytical results on the same barleys.

Omitting for the moment grades I and VII, grades II to VI fall in order of decreasing extract yield and thousand corn weight and increasing nitrogen content and diastatic power (this with one exception).

Only two centres produced Grade I barleys, so that the averages do not necessarily characterise the grade as such; nevertheless these samples have the highest average thousand corn weight and the highest extract but one, although the nitrogen content and diastatic powers do not significantly differ from those in grade V.

There is no difference in analytical data between grade VII, the non-malting barleys and grade VI, the lowest malting grade, to

explain why one is bought for malting and the other is not.

In this summary it is only possible to compare the most important analytical data; nitrogen and thousand corn weight in the barleys (which will be referred to as barley analysis) and extract obtained from the malts. The relations of the other analytical figures to grade are slight and appear to be merely a reflection of their common relations with nitrogen. The comparisons are based on 52 averages for centres, some 260 samples in all, in the first five years of the experiments 1922-26.

As might be anticipated, over this large number of samples there is a clear relation between grade and extract; although the valuations were not based primarily on extract, the barleys in the higher grades were, in general, those of low nitrogen content and yielded high extracts. There are, however, a number of exceptions and

the relation of grade to extract is not nearly as close as that of barley analysis to extract. When these valuations were submitted to statistical examination and the results expressed in the form of prediction equations¹ the error of the prediction from the grade is ± 2.3 lb. and of that from the barley analysis is ± 1.4 lb. The large "error" of the grade prediction of extract may be

partly due to the personal factor or entirely due to the fact that, in grading, importance is attached to characters in the barley other than expected extract, such as ripeness, soundness and freedom from damage. In Continental systems these have been assessed by marks, but this has not been done here, so that it is not possible to evaluate the relative importance of the different factors.

There is at present a "missing factor" in extract prediction. For instance, the Institute malts of 1924 and 1925 barleys gave extracts which averaged 2.3 lb. and 2.7 lb. below normal (judged by prediction). Similarly individual malts in other years were also low. These low extracts might well be expected to be related to factors such as damage in harvesting and threshing, in stack or to unripeness in so far as these lead to poor growth in malting. If grading had assessed these "imponderables" it would be anticipated that these low extract barleys would have been consistently given lower grades. This was found not to be so

¹ E=extract on dry malt.

P=valuation grade of barley (Grades 1-7).

N=nitrogen per cent. on dry barley.

G=thousand corn weight on dry barley in grams.

(1) $E = \text{mean extract} = 97.8 \quad \dots \pm 2.59 \text{ (68\%)} \\ \text{(See footnote, p. 296).}$

(2) $E = 101.7 - 0.856 P \quad \dots \pm 2.27$

(3) $E = 108.2 - 9.86 N + 0.14 G \quad \dots \pm 1.39$

The errors are measured by the square of the standard error and the error of the N and G prediction is only two-fifths of that from grade prices.

The equations for the predictions of extract, omitting Grade 7 barleys are :—

(5) $E = \text{mean} = 98.0 \quad \dots \dots \pm 2.55$

(6) $E = 101.8 - 0.904 P \quad \dots \dots \pm 2.23$

(7) $E = 108.1 - 9.52 N + 0.13 G \quad \dots \dots \pm 1.44$

EXTRACT PREDICTION FROM GRADING AND FROM ANALYSIS.

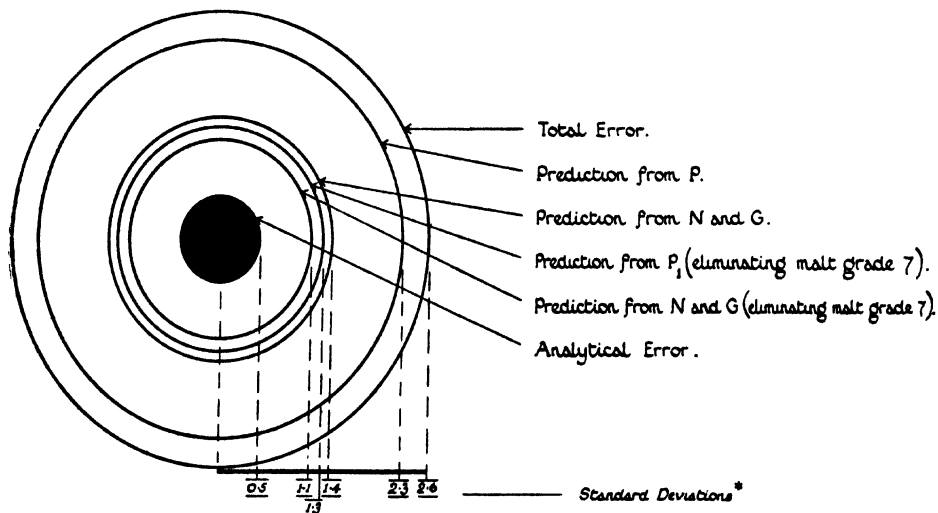


Diagram 5. The circles in this diagram show the range within which 68 per cent. of the estimates of extract would fall, if made by the various methods indicated. The largest scattering is obtained when one assumes that any given sample gives the same extract as the average of all; this is called the "Total error." A better result is obtained by working from the grade into which the buyer puts the barley by his valuation, called P in the diagram. Closer approximations are obtained by prediction from the nitrogen content and 1,000 corn weight (N and G), and still closer by taking into account only the malts finally accepted for malting and rejecting those deemed unsuitable. The circle marked P_1 (valuers grading of malt) does not refer strictly to prediction of extract because the valuer here knows the extract; it shows how he grades the malt after taking into account its other qualities. The black circle expresses the magnitude of the experimental errors; it sets the limits beyond which predictions cannot be tested.

*In brewers' lb. of extract.

as has been shown in several ways¹ and as is illustrated in Diagram 5, where the radii of successive circles are the standard errors. The decrease in area enclosed by successive rings represents the increase in accuracy.

The difficulty of assessing the value of a system of barley grading is enhanced by the circumstance that barley may be judged in two ways: from its value for making malt, or its value for making beer. Maltsters-for-sale think in terms of the malt; maltster-brewers think in terms of the beer.

(b) *Accuracy of Barley grading judged from malt grading.*

A grade for the malt was assigned on the basis of the barley valuation calculated from the malt valuation allowing for malting loss and a uniform 25s. for freight, malting costs and profits. This figure thus obtained at once gives the barley grade by reference to Table 3. The malt grade (when the extract

is known) was much more closely related to extract than was the original barley grade, that is if the new Grade 7 (non-malting) barleys are rejected.¹ The effect of the "imponderables" is still clear, as might be expected, and the grade of a malt is related to the grade of its corresponding barley.² The best way of predicting the malt grade is to take both barley grade and nitrogen content into account.³ Otherwise there are discrepancies between the barley and malt grades, *i. e.*, barleys of good appearance were graded high which, by reason of high nitrogen content, gave low extracts and were put into lower grades as malts—a losing proposition. The converse also occurs. It suggests that in barley grading nitrogen content should be given nearly as much importance as

¹ The equations are:—

For all barleys (2) $E = 101.7 - 0.856 P$.. ± 2.27

For all malts (8) $E = 102.0 - 0.847 P_1$.. ± 2.04

where P_1 = valuation grade of barley deduced as above from malt valuation. After elimination of Grade VII malts, equations (9) and (10) are obtained.

(9) $E = 101.4 - 0.641 P_1$.. ± 1.26

(10) $E = 101.5 - 6.84 N +$

0.19G .. ± 1.14

² $P_1 = 0.85 + 0.90 P$.. ± 1.30

³ $P_1 = -3.22 + 0.85P + 3.1N$.. ± 1.16

¹ There is no significant correlation between the residual differences of extract from the values predicted from barley analysis and the residual differences of barley grade predicted from barley analysis. Consequently, the addition of the grade as a factor with the barley analysis does not improve extract prediction.

RELATION OF BARLEY GRADE AND ANALYSIS TO MALT GRADE.

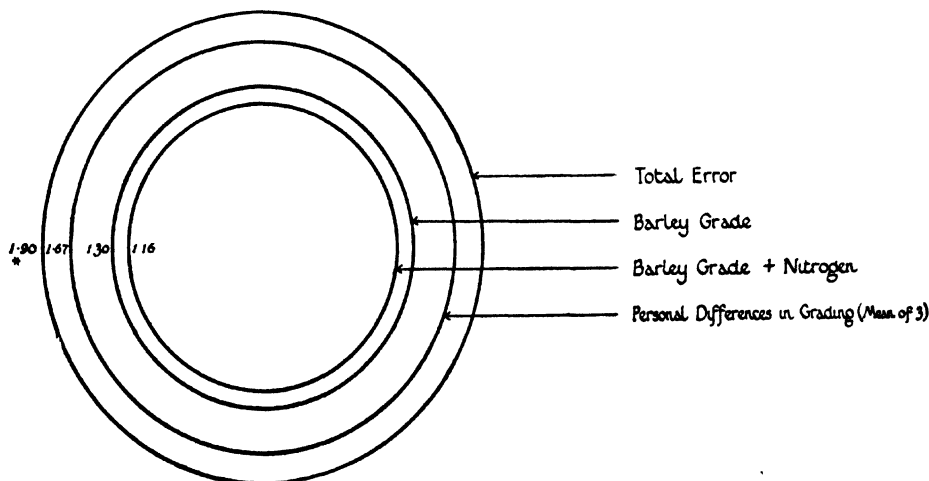


Diagram 6. The circles show the range within which 68 per cent. of the estimates of malt grade would fall if made by the various methods indicated. The largest scattering is obtained, as before, when one assumes that any given sample of malt will have the same grade as the average of all the samples. A better result is obtained from the grade assigned to the malt by the valuers, but when three independent valuations were obtained the figures are scattered over the circle labelled "Personal differences"; no doubt these differences express the different requirements of various valuers. Better agreement about grading the malts is obtained by using the barley grade, especially when this is corrected for nitrogen content.

*Standard deviations in malt grade units.

appearance.¹ This is illustrated in Diagram 6.

Comparison of the extracts obtained with the barley valuation figures over the large number and wide variety of barleys examined indicates the high bonus per lb. of extract obtained from low nitrogen barleys and the penalty for high nitrogen barleys. The results are collected in Table 5, with the cost of extract based on the average price of the various grades of barley over five years.

TABLE 5.

Nitrogen per cent. in barley.	Cost of extract pence per Brewers' lb.
Below 1.45	7.9
1.45-1.65	6.5
1.65-1.8	5.6
Above 1.8	4.8

In Table 6 figures are brought together showing the relationships between the soil on which the barley is grown, the nitrogen content, the extract obtained, the valuation and cost of a pound of extract. These are the averages for the barleys grown in the

¹ Correlation of barley grade to malt grade +0.74
 " " nitrogen content to malt grade +0.63

TABLE 6.

RELATION OF NITROGEN CONTENT, EXTRACT AND VALUATION WITH SOIL TYPES.

(First five years of Institute Experiments, 1922-1926.)

Nitrogen, per cent.		Below 1.45.	1.45-1.65.	1.65-1.8.	Above 1.8.	Total.
Numbers of Samples from :—	Fens ..	—	1	1	1	3
	Clays ..	—	5	2	—	7
	Sands ..	1	3	1	5	10
	Loams ..	8	13	6	1	28
	Chalks ..	2	2	1	—	5
		11	24	11	7	Averages.
lb. of Extract per 448 lb. raw barley	Fens ..	—	94.8	96.0	98.0	96.3
	Clays ..	—	96.2	94.8	—	95.8
	Sands ..	97.1	97.4	96.5	90.1	93.6
	Loams ..	100.8	98.0	98.6	95.4	98.8
	Chalks ..	98.5	100.2	93.0	—	98.1
Average ¹		100.0	97.6	97.0	92.0	97.2
Valuation in shillings per 448 lb.	Fens ..	—	63s.	30s.	41.5s.	44.8s.
	Clays ..	—	54.6s.	42.5s.	—	51.1s.
	Sands ..	82s.	54.2s.	54s.	36.2s.	47.9s.
	Loams ..	64.8s.	53.5s.	42.3s.	35.2s.	53.7s.
	Chalks ..	62s.	35.6s.	74s.	—	53.8s.
Average		68.6s.	52.7s.	45.2s.	36.8s.	51.8s.
Average as % ..		100.0%	76.8%	65.9%	53.6%	
Cost of Extract per lb.	Fens ..	—	8.0d.	3.8d.	5.1d.	5.6d.
	Clays ..	—	7.1d.	5.4d.	—	6.4d.
	Sands ..	10.1d.	6.7d.	6.7d.	4.8d.	6.1d.
	Loams ..	7.7d.	6.6d.	5.2d.	4.4d.	6.5d.
	Chalks ..	7.6d.	4.3d.	9.6d.	—	6.6d.
Average cost per lb. ..		7.9d.	6.5d.	5.6d.	4.8d.	6.4d.

¹ The averages given are the true averages, i.e., taking into account the number of cases as well as the average extract in the group.

first five years of the Institute experiments and refer, in each year, to barleys grown from the same seed. They show the way in which the same barleys grown on different soils tend to group themselves round a certain range of nitrogen content: *e.g.*, on the loams and clays the samples gave figures around 1.45-1.65 and higher on the fens; this is more fully dealt with in Part II of this Report. The average price paid per lb. of extract is almost exactly the same whether the barley came from clays, loams or chalks, when the barleys are grouped according to their origin, but not when they are grouped according to their nitrogen content.

The experiments given later in this section of the paper (p. 306) show that high and low nitrogen content barleys behave somewhat differently on brewing. We have at present no evidence from these results on which to base an estimate of true relative values. It may be that brewing experience provides some sufficient reason for paying so high a premium per lb. of extract from low nitrogen barleys and for deducting so large an amount per lb. of extract from high nitrogen barleys, but none has emerged from the brewing experiments.

(c) *Agreement between Barley Grade and Beer Quality.*

The maltster-brewer is presumably interested primarily in neither extract yield nor barley appearance, but in beer characters such as flavour, brilliancy and stability. It is therefore necessary to relate the barley grades not to malt, but to beer in brewing tests. The Institute's preliminary work on these lines and the requirements of the maltster-brewer will be considered in the two following sections. Most of the work was done with English two-rowed barleys of two related varieties; the effect of variety has not yet been considered. An English-grown six-rowed barley (F.112) was, however, studied; it compared well with Californian barley in analysis, but was higher in moisture content, and required a rather long rest between sweating and malting.¹ No drainage difficulties were experienced with it in the mash tun.

Large Scale Brewing Experiments.

During the years covered by this review a number of large scale brewing trials have been carried out to test various points as they arose; *e.g.*, the possible effect of fertilisers

¹H. Lloyd Hind, this *Journ.*, 1930, 435.

TABLE 7.

LARGE SCALE BREWING TRIALS.

	No.	Barley.			Malt.			Beer Flavour.
		N. %.	Valuation S.	N. %.	P.S.N. %.	Extract.	Valuation S.	
1926 A	1	1.52	46	1.48	0.49	100.2	80	Rougher.
	2	1.54	46	1.54	0.50	99.5	85	
1927 B	3	1.48	48	1.46	0.50	100.6	78	1
	4	1.49	50	1.41	0.50	100.7	78	2
	5	1.52	50	1.46	0.49	100.8	78	3
C	6	1.41	—	1.43	0.56	100.9	85	} Equal.
	7	1.34	—	1.31	0.52	102.0	85	
D	8	1.40	49	1.40	0.54	101.5	82	} 3
	9	1.42	48	1.43	0.52	101.5	82	
	10	1.50	50	1.43	0.55	101.8	82	
	11	1.58	46	1.51	0.55	101.8	82	
1928 E	12	1.55	38	1.52	0.47	99.0	45	} Equal.
	13	1.54	38	1.47	0.46	99.4	55	

applied to the barley on the flavour of the beer. As the number of experiments is limited the conclusions drawn are only tentative, but they appear to indicate a relation between nitrogen content and flavour, a better flavour with lower nitrogen content, which is worthy of further investigation. The particulars of the trials will be given in a later report, but the results are recorded in Table 7. The beers were usually

tasted by a number of brewers, and consensus of opinion placed them in the order indicated in the Table, but the differences were in all cases very small.

The results are clearer when expressed in the form of a diagram (Diagram 7.).

Small Scale Brewing Experiments.

A number of small scale brewings have been made in the Rothamsted laboratory with the

RELATIONS BETWEEN BEER FLAVOUR AND DIFFERENT VALUATION METHODS.

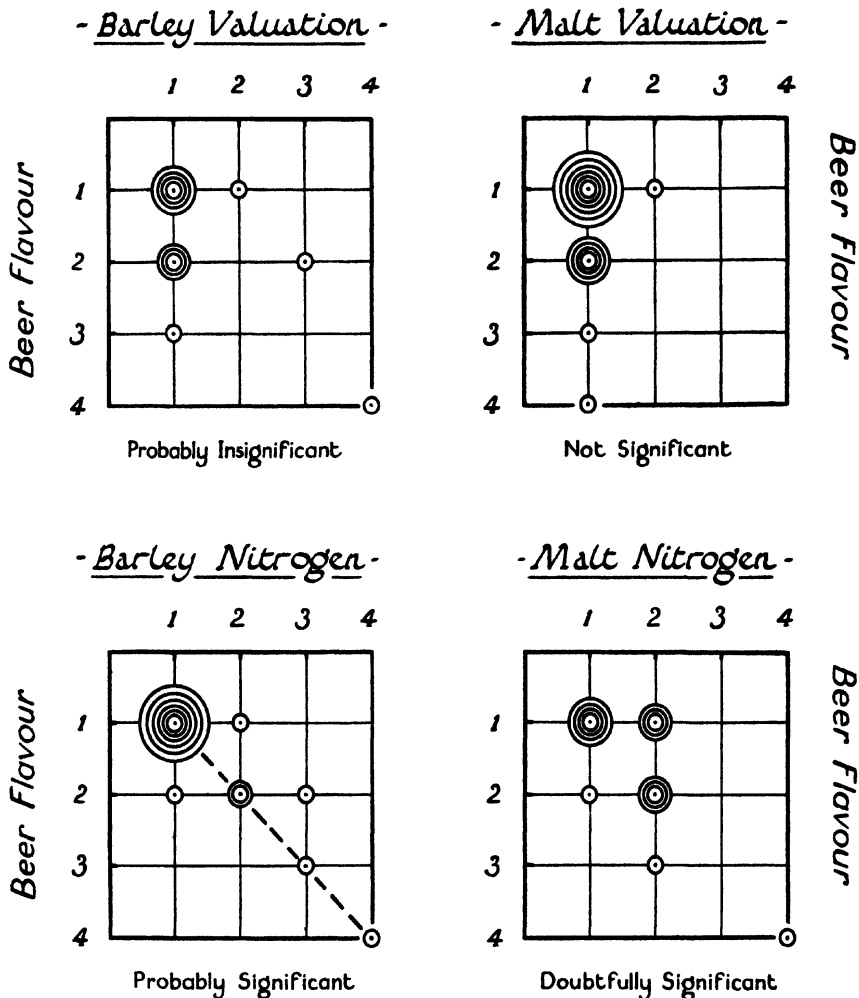


Diagram 7. This summarises the judgments of the expert tasters on the flavour of the beers compared with the nitrogen content and valuation of the barleys and malts from which they were brewed. The best agreement is with the nitrogen content of the barley; the samples of lowest nitrogen content (1) gave, in all cases but one, better-flavoured beers than those of higher nitrogen content brewed at the same time and under comparable conditions; as the nitrogen content increased so the flavour fell off, with a few minor exceptions. the valuations of barley and of malt showed little or no relation to matured beer flavour.

apparatus already referred to. Some fifteen sets of nitrogen comparisons have been carried through, the results of which will be published shortly. In the main they agree with the results of the large scale brews, and support current brewing practice.

The experimental results agree in indicating that beers from high nitrogen barleys compare as follows with those from low nitrogen barleys:—

- (1) They taste better at first.
- (2) Later on the flavour becomes rougher, while the low nitrogen beers develop a finer more delicate flavour.¹
- (3) They give a better copper break.
- (4) The yeasts tend to develop more bacterial infection.

There is some evidence for an optimal ratio of nitrogen to carbohydrate for yeast nutrition.

These differences were noted when the barleys or malts differed more than 0.1 per cent. in nitrogen content, and, as far as can be judged, the large scale results support them, but the latter are indecisive, as differences in nitrogen content were small.

The laboratory results require much further extension, but, as far as they go, they afford an explanation of current practice; for they support this in favouring the use of low nitrogen malts for brewing the more delicate, higher gravity, longer matured beers, and the use of higher nitrogen malts for those beers which are required for quick sale. This generalisation reconciles the apparent discrepancy between the two present-day schools of thought in brewing, *i.e.*, those brewers who urge the use of low nitrogen malts while

others recommend those of intermediate nitrogen content. The latter school was represented by the late A. Chaston Chapman.²

The small scale results show decreased yield of yeast in low nitrogen worts, and some evidence of yeast weakness in fermentation and attenuation.

This problem is one of the most important still remaining for further experiments. The evidence raises acutely the question of the relation between market valuation and true brewing value.

SUMMARY OF QUANTITATIVE RELATIONS.

PART I.

Quantitative expressions can now be given for the relations established in the preceding pages.

(a) Composition of Barleys.

The mean nitrogen content in the first five years (1922-26) of the Institute experiments was 1.60 per cent.; 68 per cent. were within 0.22 of this figure, *i.e.*, between 1.38 per cent. and 1.88 per cent.

The quantities of individual proteins are very closely related to the total nitrogen content and the thousand corn weight. For example, the protein percentages in F.112 can be stated as

$$\begin{aligned}\text{Salt-soluble N\%} & \dots = 31.5 + 46.6 N_1 - 75.1 N_1^2 \\ \text{Hordein N\%} & \dots = 27.5 - 46.6 N_1 + 75.1 N_1^2 \\ \text{Glutelin N\%} & \dots = 41.0\end{aligned}$$

where N_1 = grams of total nitrogen per 1000 corns.

There is evidence, as yet preliminary, that the individual carbohydrate quantities can be stated similarly in relation to the total carbohydrate. As an instance, the average percentage of "insoluble carbohydrate" in six varieties is given together with their varietal extract constants:—

	I_1	S.E.	A	S.E.	
Standwell	7.8 ± 0.1		109.7 ± 0.4		(high
Spratt-Archer..	8.1 ± 0.2		108.6 ± 0.1		extract)
Plumage-Archer	8.3 ± 0.2		108.3	—	
Indian ..	10.5 ± 0.2		104.8 ± 0.2		
F.112 ..	10.9 ± 0.4		103.0 ± 0.3		
Atlas (Californian)	10.6 ± 0.1		101.5 ± 0.3		(low
					extract)

I_1 = % of $\frac{\text{insoluble carbohydrate}}{\text{total carbohydrate}}$, mean value.

A = Varietal extract constant, mean value. See below.
S.E. = Standard error of mean.

The mean percentage of P_2O_5 found in English barleys (1922-25) was 0.96 per cent. on dry barley; 68 per cent. of the results were within 0.08 of this figure.

¹ This was the expert opinion, but some who tasted consistently preferred what they called the "fuller flavour" of the experts' "rougher" beer.

² See this *Journ.*, 1922, 43: "It is obvious that, without an estimation of the different forms of nitrogen occurring in the wort it is impossible to say with certainty what proportion of these substances is available for purposes of yeast nutrition. Such a differentiation is, of course, impossible in technical analysis, but my very extensive experience over a great many years has shown me that in the main total soluble nitrogen (c) percentage does afford an indication of the yeast-feeding properties of the malt. When this percentage is small—that is to say, in the neighbourhood of 3 per cent. in the case of English malts—the yeast-feeding properties of the malts in question are found in practice to be poor, whereas when the proportion is in the neighbourhood of 4 per cent. much better results, from the point of view of yeast-nutrition, are obtained in the brewery."

(c) The reference intended is to soluble proteins, *i.e.*, $N\% \times 6.25$.

(b) Barley—Malt Relations.

All the figures customary in malt analysis are related (a) to the barley nitrogen content, (b) certainly in some, and possibly in all cases, to thousand corn weight, (c) probably to a hypothetical "missing factor" connected with behaviour on germination, (d) as is well known to malting conditions.

In addition, extract is strongly influenced by variety.

The effects on extract of variety, nitrogen content (N) and thousand corn weight (G) can be stated¹ as constants in the form

$$E = A - 10.5 N + 0.2 G \dots \pm 1.4 \text{ lb.}$$

where E = Extract in brewers' lb. per quarter of dry malt. (I. of B. standard method).

N = Nitrogen per cent. on dry barley.

G = weight of thousand corns dry in grams.

A = a varietal constant.

Alternatively, the varietal, thousand corn weight and nitrogen effects are allowed for in:—

$$E = 134.7 - 9.0 N - 2.8 I \dots \pm 1.0 \text{ lb.}$$

where I = per cent. of "insoluble carbohydrate" on dry barley.

The relation of diastatic power to nitrogen content, thousand corn weight and kilning temperature, and the relations of permanently soluble nitrogen, cold water extract, malting loss and colour to nitrogen content, can also be stated numerically, and the figures shown to be significant.

(c) Quality Relations.

The composition, as defined above, enters into the value of the product, and the question arises how far intangible quality effects yet remain unmeasured.

¹This *Journ.*, 1933.

Two types of judgment are possible, (1) from malt, (2) from beer.

(1) From Malt.

The barleys were divided into seven grades—six malting grades and a seventh for non-malting barleys—and the following relations have been found.

The barley grade (P) is related to the nitrogen content (N) as follows²:—

$$P = 4.46 = \text{mean} \dots \dots \dots \pm 1.6$$

$$P = -1.1 + 3.45 N \dots \dots \dots \pm 1.4$$

The malt grade (P₁) is related to the barley grade and the barley nitrogen content as follows²:—

$$P_1 = 4.85 = \text{mean} \dots \dots \dots \pm 1.9$$

$$P_1 = -3.95 + 5.5 N \dots \dots \dots \pm 1.5$$

$$P_1 = 0.85 + 0.90 P \dots \dots \dots \pm 1.3$$

$$P_1 = -3.22 + 0.85 P + 3.1 N \dots \dots \dots \pm 1.2$$

The valuation scale usually accords low nitrogen barleys a premium considerably in excess of the greater extract yield, and for this no analytical reason is available.

(2) From Beer.

Small scale brewings suggest that, up to a fortnight after racking, moderately high nitrogen barleys give a better initial beer flavour, which afterwards deteriorates. Large and small scale brewings suggest that matured beer flavour is better from lower nitrogen barleys.

These results reconcile the two schools on the nitrogen question in modern brewing, suggesting that barleys of moderate nitrogen content are better for making light short-storage beers, and barleys of lower nitrogen content are better for heavier longer matured beers.

²The results for 1922-26 inclusive were used for the calculations.

PART II.

SECTION I.

The Requirements of Maltsters and Brewers.

The requirements of British maltsters have been set out three times in the past 30 years for the benefit of the home farmer in terms which show considerable measure of agreement.

Dr. E. S. Beaven in 1905 read a paper before the Farmers' Club¹ wherein he emphasised (as in his earlier papers) the need for low nitrogen content and good maturation: he quoted a 17th century writer² to the effect that the barley should

¹ *Journal of the Farmers' Club*, December, 1905.

² E. Lisle, "Observations in Husbandry" (1666(?). 1722: published by his son in 1757.)

be "a pale lively yellow colour with a good bright whiteness in it and if the rind is a little curdled, so much the better": it should not be "blackish at the tail." Beaven states that soils of recent formation are most suited to barley, and the most appropriate seasonal conditions for yield appear to be coolness and dryness, yet with many exceptions; drought also was distinctly injurious. For quality the conditions were in some ways reversed: warmth improved the quality, but deficient rainfall in the latter part of the growing season injured it. Good malting quality often went with low yield: nevertheless manuring with nitrogenous fertiliser and superphosphate was likely to ensure both yield and quality.

In the discussion on the paper considerable stress was laid on the circumstance that the prizes at the Brewers' Exhibition went to barleys grown without manures, and for long the advice usually given was to refrain from manuring if good quality were desired.

In 1926 H. M. Lancaster¹ set out the following as the maltster's requirements:—

(1) The barley must germinate to nearly 100 per cent., i.e., it must not be heated in the stack or "mow-burnt."

(2) It must produce "tender" or friable malt, in other words it must modify completely.

A buyer not restricted to price can, he stated, select barleys possessing these characters by empirical judgment, but if shortness of supplies or restrictions of price compel him to buy cheaper material it is difficult for him to choose without the aid of the laboratory.

Other things being equal, barleys with a nitrogen content of between 1.0 and 1.5 per cent. are more likely to make "tender malts" than those containing more than 1.5 per cent.

(3) A bright appearance in the barley is associated with a bright appearance in the malt and this may add greatly to the selling price even though no more extract be obtainable therefrom. As to whether the higher price was justified, Mr. Lancaster expressed no opinion.

Finally, in 1928, R. V. Reid attended a Conference called at Rothamsted between barley-growing farmers, expert maltsters and the Research Staff of the Institute of Brewing, and then he laid down the following for the guidance of producers, emphasising the fact that they are only general requirements, subject to modification for special purposes.²

(1) *Characters wanted.* Grain grown on barley-land, well-ripened, of good shape,³

uniform, carefully threshed,¹ thoroughly sound, with a nitrogen content not exceeding 1.6 per cent., free from weed contamination and capable of producing first class malt.

(2) *Characters not wanted.* Hard, steely, heated, badly threshed, skinned and broken corns, grown corns, high nitrogen content.

Some of these requirements have to do with harvesting, threshing and storage and as such are outside the Committee's sphere, but some have to do with the conditions of growth of the barley and these have been investigated.

The Brewers' requirements. We have been able to find no corresponding summaries of the brewers' requirements in this country. Several different but arbitrary systems of assigning marks for the various qualities have been set up in different Continental countries² but they lack definite experimental basis. As far as we know, the relations between nitrogen and beer flavour given in the preceding sections afford the only available material capable of being expressed numerically.

From the foregoing paragraph it is clear that the essential properties of the barley grain are its degree of maturation, nitrogen content, variety, soundness, moisture content, 1,000 corn weight and capacity for giving high extract. The purpose of the field experiments of the Institute was to find how these properties and the 'imponderable' qualities assessed by the valuation are related to the soil, season and manuring. This information affords a sound basis for devising methods of producing barleys suitable for the various requirements of maltsters and brewers, or, where control is impossible because the factors concerned are not in the farmer's hands (e.g., the weather), then it opens up the possibility of making reasonable forecasts of the properties of the barley from a knowledge of the conditions under which it has been grown.

How the farmer has tried to meet these requirements. Usually this has been done by sowing grain found to be acceptable. This led to the widespread use of Chevallier in the 19th century in place of the older

¹ *J. Nat. Inst. Agric. Botany*, Cambridge, 1926, Vol. 1 No. 5.

² Rothamsted Conference Reports No. 7, *Malting Barley*, 1928 (Rothamsted Experimental Station).

³ By good shape is generally understood a round plump grain rather than a long narrow one, Mann and Harlan (Bull. 183, U.S. Dept. Agric., 1915; this *Journ.*, 1916, 73) justify this preference on the grounds that in a round grain the enzymes exerted by the embryo have a shorter distance to travel to the end of the grain than in a long one, and are better able to complete the modification of the grain. There are, therefore, no hard ends left.

¹ In particular, the grains must not be broken or chipped, or they will be attacked by moulds. The Ministry of Agriculture has issued a Bulletin to farmers wherein they suggest that a little of the awn should be left on, rather than that the machine be set too closely.

² See T. J. Harrison, *Sci., Agric.*, 1929, 9, 599.

sorts: later Chevallier was displaced by Archer in the South Country and by Goldthorpe, an earlier ripening variety, in the North. With the widespread interest in plant breeding of the early years of the 20th century there came a number of hybrids, most of which have now been replaced by Plumage-Archer (1905) and Spratt-Archer (1920)¹.

These newer sorts combine high yield, low nitrogen content and high extract. The result has been a progressive increase in the extract obtained from malt which is shown in the data kindly supplied by large breweries and collected for us by Mr. H. Stanley Taylor (Table 8).

It has, however, been claimed that the reduction in nitrogen content has now gone far enough, and satisfactory varieties have recently been produced which combine high extract with a higher nitrogen content than is found in the standard sorts.

SECTION II.

I.—The effect of Soil, Season, Manuring and other Factors on the Yield, Composition and Valuation of Barley Grain.

At the time the Institute of Brewing experiments began, the chief experimental fields for the study of barley were Hoosfield and Agdell field at Rothamsted, and Stackyard field at Woburn. On Hoosfield, barley has been grown every year since 1852, except for one fallow in 1912, and on Stackyard every year since 1876, except for two years'

fallow in 1927 and 1928; on Agdell field it has been grown in rotation since 1849.¹ The Hoosfield barley was examined by Munro and Beaven in 1897, and the Agdell field barley in 1900². The fact of continuous growth on Hoos and Stackyard fields simplifies the experiment for a good many purposes, but makes the conditions unlike those of practice, where barley is grown in a rotation. This might have been overcome by help of the Agdell field results, but a more serious difficulty is that the barley is now often not of good malting quality. In the ten years during which the Valuation Sub-Committee have seen it, they have only once placed it head of the list, and not infrequently have given it only a modest valuation. Its nitrogen content is usually about 1.5-1.6 per cent. The Woburn barley (Stackyard field) has higher nitrogen content, usually about 1.9 per cent., and commonly a low valuation.

A number of conclusions can be drawn both from the Rothamsted and the Woburn data, but it does not follow that they would hold for malting barley grown in the very different conditions in which the malting barley of Great Britain is produced. Field experiments on a comparatively small scale scattered over the areas normally producing malting barleys would have sufficed to ascertain how far the conclusions from Rothamsted and Woburn hold generally, but in the early years of the Committee's work it was also

¹ For an outline of the history of English varieties see H. Hunter, Rothamsted Malting Barley Conference Report, No. 7, 1928.

¹ *J. Roy. Ag. Soc.* 1897, 58, p. 65; 1900, 61, p. 185.

² The experiment began in 1848 with a root crop.

TABLE 8.

BREWERS LB. OF EXTRACT PER 336 LB. OF MALT.
Averages over 5 years periods.

	1899-1892	1902-1906	1907-1911	1912-1916	1917-1921	1922-1926	1927-1931
<i>Chevallier Type.</i>							
Pale ale malt ..	—	97.92	97.86	98.52	98.20	99.84	100.06
Mild ale malt ..	—	97.64	97.34	96.98	96.62	98.20	98.68
<i>West Country Breweries</i>							
1. (87.5) ³	—	—	91.90	93.52	92.18	93.60	95.24
A	—	—	—	—	—	97.06	98.37
B	—	—	—	—	—	96.62	98.62
C	—	—	—	—	—	97.40	98.70

³ Not true average but figures taken roughly and kept as private notes. The improvement is not wholly attributable to the barley, since there has been an increase in the efficiency of the extraction process in the brewing.

necessary to obtain large samples of barley of known origin for the large scale maltings which formed part of the original programme. So long as these were being attempted, therefore, the field experiments aimed at producing 4 quarter samples, but as soon as the large scale malting experiments were completed, the scale of the field experiments was greatly reduced.

In the field experiments the same lot of seed was used for all the centres ; the results were, therefore, strictly comparable. Plumage-Archer was the variety chosen, it having already become the most widespread of all malting varieties. The first series of large scale experiments continued without change for four years, and provided a great mass of figures which have been examined in detail ; they brought out some results that agreed entirely with those previously obtained at Rothamsted and Woburn, others that differed, and others, again, that are new. A second series of more critical experiments was then set up on a much smaller scale, and confined to a few centres, and these, after the first two years, were more fully elaborated in order to be suitable for statistical examination, which would settle beyond dispute the various points that had been raised. The figures for the first five years are published in the interim reports ; the later figures, being more detailed, and requiring several years' accumulation before they could be regarded as significant, were not ; they are all now, however, collected as an appendix to this Report.¹

The more purely agricultural aspects of the work will be summarised only briefly, they having already been published in the appropriate agricultural journals, and a connected account for the agricultural expert is being issued shortly.

From the outset the field experiments proved of great value to agricultural experts and the results were much used in farmers' lectures and discussions, in demonstrations and general advisory work ; the results which showed the possibility of increasing yield without loss of quality were of special interest. It had been the usual advice to apply no manure if a good malting sample were desired, and to trust to a favourable season for a good yield.

¹ The data of agricultural interest are published in the Rothamsted Annual Reports.

This agreed with analysis of Hoosfield barley, showing that the unmanured barley had the lowest nitrogen content, while barley manured with sulphate of ammonia or nitrate of soda contained much more (p. 323) ; the amount was reduced by adding potash and phosphatic manures, but not to the level of the unmanured barley. The Institute experiments showed that the withholding of manure was not necessary, and that appropriate nitrogenous manuring applied under specified conditions increased yields by some 5 or 6 bushels per acre, not only without detriment to nitrogen content or valuation but frequently with an improvement in the valuation. It is significant that shortly after this information was widely spread among farmers the yields of barley, which had been fairly steady for a number of years, began to rise and went on rising continuously till 1930, when the general agricultural slump made farmers quite uninterested in yields, so that they fell again badly. The sales of artificial nitrogenous fertilisers also moved in the same way. The more extended use of Plumage-Archer bred by Dr. Beaven in 1905, of the improved strain introduced in 1924, and of Spratt-Archer introduced into England in 1920, allowed the additional yields to be obtained and, but for these new varieties, the yields of 1930 and 1931 would probably have been even lower. No other crop showed steady increased yields like this ; wheat showed no increase at all, and oats an irregular though less marked increase which, however, is not necessarily unconnected with the barley work since the same type of manurial treatment can be given to both.

The essential facts brought out by the Institute's experiments, and by the concurrent investigations of other workers at Rothamsted, fall into two groups.

It was long supposed that the percentage of nitrogen in the grain was largely determined by the conditions at the time of ripening : during the earlier stages of grain formation the nitrogen compounds were supposed to enter the seed in larger amounts relative to the non-nitrogenous compounds, starch, etc., than during the later stages. In good ripening seasons, therefore, more starch was supposed to accumulate than in those of poorer ripening.

This was shown to be incorrect by Brenchley in 1912, who found no decrease in

EFFECT OF INCREASING NITROGEN FERTILISER ON YIELD AND COMPOSITION OF BARLEY GRAIN.

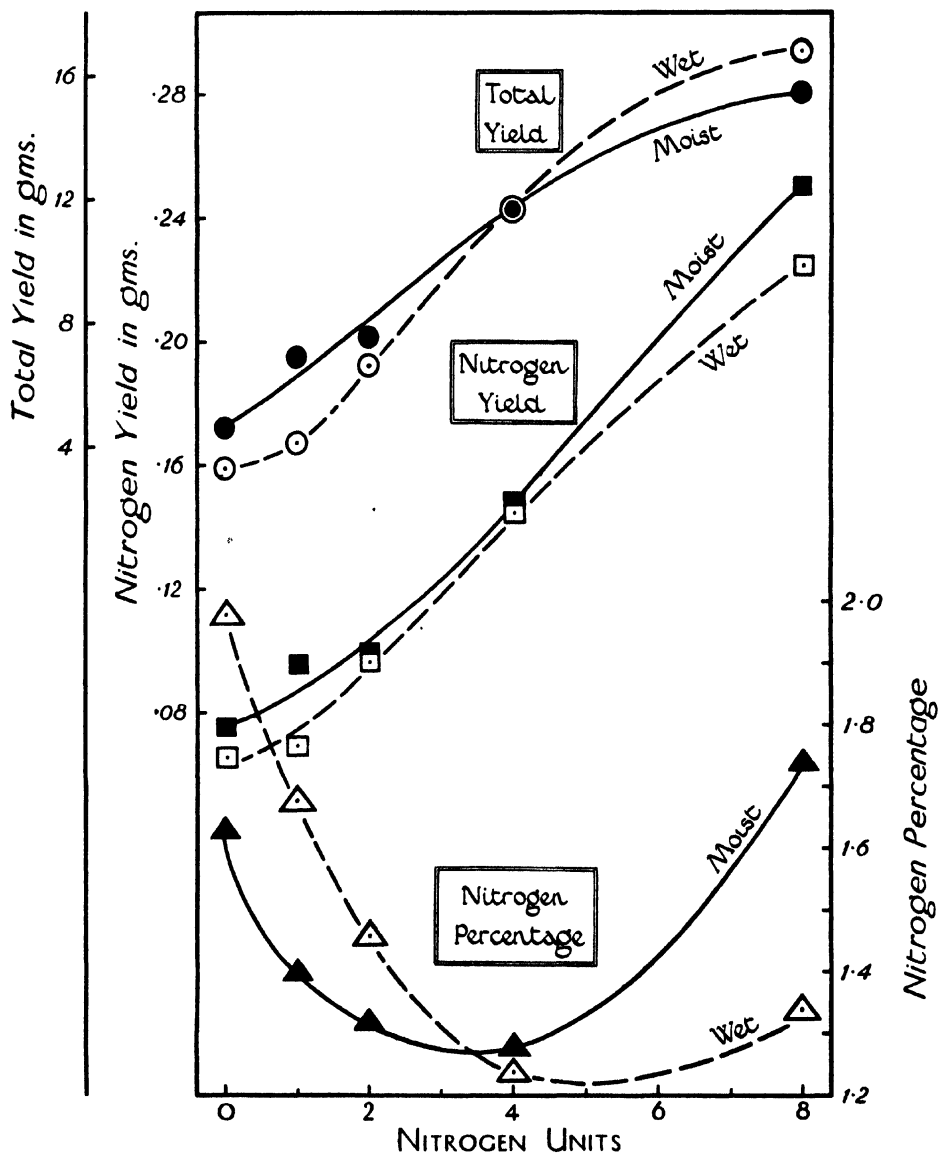


Diagram 8. This shows the yield of barley grain, its uptake of nitrogen and its nitrogen percentage when grown under restricted and under fuller conditions of water supply ("moist" and "wet") respectively. As the nitrogen supply increases, so the uptake of nitrogen ('Nitrogen yield') increases also, but the yield increases still more, so that the nitrogen percentage falls. Beyond a certain limit, however, the increase in yield no longer keeps pace with the increase in nitrogen uptake, so that the percentage of nitrogen in the grain now rises.

This limit is not fixed, but changes with the water supply and other conditions. (Woburn Pot Culture experiments, 1931.)

proportion of nitrogen as the grain developed; if anything, indeed, there was a slight rise.¹ This result was parallel to an earlier one obtained with wheat², and it is confirmed by the Institute's experiments and by those of the Rothamsted Staff. These show that the percentage of nitrogen in barley is almost completely settled before the end of June and is but little affected by the weather during the time of ripening in July or August. Table 18 shows the percentage of nitrogen forecasted at the end of June in some of the Woburn barleys, and the percentage actually found in the grain after harvest some six weeks later. The agreement is sufficiently close to show that it is during the months April, May and June, and not during the ripening time, that the nitrogen content is chiefly determined and the other properties connected with it: the proportion of hordein, of glutelin, of salt-soluble nitrogen compounds, the amount of diastase, and the amount of extract obtainable from the malt. All these could be forecasted with considerable accuracy before the final stages of ripening have begun. This will be more fully discussed further on. This change of view is of more than academic importance, for it has considerable practical possibilities.

On the other hand, the weather during ripening governs the final stages of maturation and the germination properties of the grain and all the malting value associated therewith, which sufficiently accounts for the great importance attached to July and August weather in determining the value of the barley.

The second group of results are concerned with the conditions governing the percentage of nitrogen in the grain or, what is substantially the same thing, in the stream of material that goes to build up the grain. Its composition is shown to be determined by the conditions in spring and early summer, especially by the relation between the supply of available nitrogen in the soil and the power of the leaf to build up carbohydrate. This is shown in Diagram 8. The yield of grain increases as the supply of available nitrogen in the soil increases; beyond a certain point the increase falls off. The nitrogen content of the grain, however, does not

increase in this way; it remains almost unaltered, or even falls for the first one or two increments of nitrogen in the manure, but then it begins to rise fairly rapidly. The samples thus fall into two groups: those for which the nitrogen percentage only slightly alters with changes in the amount of nitrogen available to the crop, and those which are more sensitive to nitrogen supply, where additional nitrogen causes the percentage of nitrogen in the grain to increase (Table 9). The point where one relation ends and the other begins is not fixed, it varies with the conditions (Diagram 8).

TABLE 9.
Large Scale samples, 1922-1925 series.

	Nitrogen per cent. less than 1.6		Nitrogen per cent. 1.6 or more	
	Nitrogenous fertiliser	None.	Nitrogenous fertiliser	None.
Per cent. Nitrogen in grain ..	1.45	1.43	1.81	1.71
Yield, bushels per acre ..	41.8	34.6	40.2	38.5

A point of great practical importance brought out by the experiments is that it makes no difference whether the additional nitrogen comes from manure or from the soil, so long as it becomes available to the plant at the same time.

The experiments have shown a number of ways in which the two groups of samples differ in the field, and they have allowed of the reconciliation of a certain number of apparent contradictions, it being shown that one observer might be dealing with barleys on the rising part of the curve (Diagram 8), and another with barleys on the flatter part. The importance of the curve lies in the fact that the barleys on the flatter part include most of the malting samples, while those on the rising part are mostly feeding barleys. With increasing manure the yield rises, even when the nitrogen percentage does not; and the agricultural side of the work has consisted in showing how to push up the yield without overstepping the boundary that divides the flatter part from the rising part of the curve.

The Wellingore barleys and others of the Institute centres are typical of samples on the flat part of the curves, the Woburn continuous

¹ W. E. Brenchley, *Annals of Botany* 1912, 26, 903.

² W. E. Brenchley and A. D. Hall, *J. Agric. Science*, 1909, 3, 195.

barleys and some of the Hoos barleys are usually on the rising part, and the Rothamsted and Woburn rotation barleys are about the junction of the two. The soil conditions chiefly determine the region on the curve within which the barley samples normally lie, while the season determines their actual position. Nitrogen contents below about 1.4 are, as a rule, obtained only under favourable natural soil conditions and, apart from certain treatments discussed later, cannot be produced at will on other soils, although they may occur in specially favourable seasons. The effect of manuring varies according as the nitrogen content of the grain is low or high. If the natural conditions produce grain of low nitrogen content, its yield can be increased by nitrogenous manuring, not only without detriment to quality, but frequently with an improvement; if, however, the soil conditions are such that the barley normally contains 1.6 or more per cent. of nitrogen, then the effect of nitrogenous manure is usually to raise it still higher, and no known scheme of manuring will reduce it to an average level of about 1.4 per cent. This raising of the nitrogen content of barley can be brought about easily in several different ways in sharp contradistinction to the difficulty of lowering it; the experiments have shown how one can obtain on the same farm, and with the same variety of barley, samples of grain ranging from 1.3 to 2.2 per cent. of nitrogen.

I. FACTORS AFFECTING YIELDS.

(a) *Soil Conditions and Fertilisers.*—The summaries of the yields for all the large scale (1922-25) experiments are given in Table 11. The fen soil gave much the highest average yield, followed by the chalk, the loam and the clay, the sand coming last; the variations in yield from year to year were, however, much greater on the light than on the heavy soils. The effect of manures has been discussed in the earlier reports, and need only be summarised: on the fen it is only slight, on the others it is to raise the yield. Of the three fertiliser constituents, nitrogen is the only one that is consistently effective, and its action, while varying with season, is on the average of several years much the same on all except the fen soils; the 21 lb. added per acre in the fertiliser gave the following increases in bushels per acre—:

TABLE 10.
Effect of Nitrogenous Fertiliser on Yield.

	Heavy loam.	Loam.	Chalk Loam.	Sand.	Fen.
Increased yield ..	5.3	5.7	5.7	4.6	2.6
Mean yield ..	32.5	39.6	45.1	26.7	52.5

In addition to these increases in yield the nitrogenous fertiliser reduced the variability from season to season (Table 17).

The close similarity in effectiveness of nitrogen on the chalk, loam, medium loam and heavy loam soils suggests that, as between the groups, the influence of soil type is not itself very great, and the differences in mean yield between them could be attributed to differences in amount of available nitrogen derived from crop residues or manure. The behaviour of the fen could be explained in the same way; the low effectiveness of nitrogen arising from the fact that there is already enough present, as shown by the high yield.

The different soils, however, differ in another important respect; their power of retaining water and supplying it to the growing plant in sufficient or excessive quantity. This, no doubt, accounts for the large difference between the sands and the loams, and for the smaller but clear difference between loams and heavy loams; differences which in some seasons make the one and in some seasons make the other the more productive.

The close agreement between the results of the 1st and of the 2nd series is very gratifying in view of the rigid conditions under which the latter were carried out. Much of the work of the Institute was necessarily based on the first series, and it is satisfactory to have this evidence of its trustworthiness.

While the nitrogenous fertiliser (1 cwt. sulphate of ammonia per acre) has added on the average 5 bushels per acre to the yield at a cost of about 8s., the superphosphate has added only 1 bushel and the potash has been on the whole without effect. This constitutes one of the most striking differences from the Hoosfield results, where phosphate produces impressive effects on barley. The difference is, however, easily explained; phosphate is as essential as nitrogen to the plant, but it has the advantage

TABLE 11.

INFLUENCE OF SOIL TYPE AND MANURING ON YIELD OF BARLEY. *Large Scale Experiments 1922-1925.*

Bushels per Acre.

Soil.	No Manure.	Sulphate of Ammonia.			Phosphate and Potash only.	Average.
		Plus Potash.	Plus Phosphate.	Plus Phosphate and Potash.		
Clay	28.3	34.3	36.4	33.2	28.0	32.0
Loam	35.1	41.6	43.2	43.8	38.3	40.4
Sand	22.6	28.8	27.7	28.4	23.6	26.2
Fen	51.1	52.8	53.3	53.9	51.3	52.5
Chalk	44.8	46.6	46.6	46.6	40.9	45.1
All Soils ..	33.5	39.0	39.9	39.9	34.8	37.4

Summary.

	No Manure.	Potash only.	Phosphate only.	Nitrogen only.	Nitrogen (Sulphate of Ammonia).			Phosphate and Potash only.
					Plus Potash.	Plus Phosphate.	Plus Phosphate and Potash.	
1st series ..	33.5	—	—	—	39.0	39.9	39.9	34.8
2nd series ..	41.1	41.9	41.9	46.8	45.7	47.6	48.0	41.4
Hoosfield* ..	13.4	14.3	19.0	23.7	25.8	35.8	39.3	19.0

Average increases given by fertilisers, bushels per acre.

	Sulphate of Ammonia (1 cwt. per acre).	Superphosphate (3 cwt. per acre).	Sulphate of Potash (1 cwt. per acre).
1st series (1922-1925) ..	5.1	0.9	Nil.
2nd series* (1928-1932) ..	5.4	0.8 ² 2.3 ³	0.06

* Omitting Woburn, 1928-29.

² Without sulphate of potash.

³ With sulphate of potash.

TABLE 12.

ADDITIONAL YIELDS OVER UNMANURED PLOT.

Effect of phosphate.				Effect of nitrogen on action of potash.		
Series 1.	Complete fertiliser.	No Phosphate.	Difference.	Sulphate of Ammonia only.	Sulphate of Potash only.	Sulphate of Ammonia + Sulphate of Potash.
Light Sands	+5.8	+6.2	-0.4	—	—	—
Other soils	+6.6	+5.4	+1.2	—	—	—
Series 2.						
Light Sand ¹	+5.4	+12.3	-6.9	+12.2	+14.3	+12.3
Other soils	+6.9	+4.6	+2.3	+5.7	+0.8	+4.6

¹ Woburn only.

that it persists longer in the soil, so that the barley can make use of dressings applied to the preceding crop. In the old Norfolk rotation this is roots usually heavily manured with superphosphate; in later modifications another cereal crop is inserted between the barley and the roots. Rarely, however, is the barley in practice more than two years distant from a good dressing of superphosphate, and sufficient remains in the soil to satisfy its needs. Modern changes in husbandry are tending to eliminate the root crop from many farms, and with it the regular and heavy dressings of superphosphate that are responsible for much of the ineffectiveness of direct dressings in these experiments. The Rothamsted experiments show that barley soon begins to suffer once the phosphatic dressings are discontinued.

The fertilisers differ not only in their average effectiveness, but in the consistency of their action. Nitrogenous fertilisers nearly always give additional crop, though the increase may be only small. Phosphate, however, is sometimes beneficial and sometimes harmful; on the average the two effects nearly cancel. At the Norfolk centres the superphosphate was consistently beneficial, adding three or four bushels per acre to the crop. On the light sands, however, it sometimes produced definite harmful effects significantly lowering the yield.

Potassic fertilisers are also variable in their effects, but in a different way from phosphate: they increase the yield on light sands. A further important difference is that a mixture of sulphate of ammonia and phosphate produced the sum of the effects of both used separately, while a mixture of sulphate of ammonia and sulphate of potash produced no more effect than either separately.

The effects are set out in Table 12.

Whether this failure of potash and nitrogen to supplement each other is due to limitation of growth by a soil factor such as

lack of water or a harmful excess effect produced by the mixed salts, is not known. The result, however, differs from that obtained by Wiessmann and Schramm¹ on sandy soils in Germany: here the effect of nitrogen was enhanced by the addition of potassic fertiliser and *vice versa*.

(b) *Season*. The effect of season on yield is shown in Table 14. As between one season and another the average yields varied only by 17 per cent.; on the manured soils the percentage variation from season to season was less than on the unmanured.

The effectiveness of the 21 lb. nitrogen (the amount contained in 1 cwt. sulphate of ammonia, added per acre) differed in the different seasons, though not over several seasons; the average increases it gave at the Institute centres, in bushels per acre, are shown in Table 13.

Numerous attempts have been made by the Rothamsted staff to characterise good and bad yielding seasons and some success has already been obtained. The problem is difficult, and the simple rules and relationships which seem to hold for a short number of years break down on further examination. Rainfall presents the simplest case. It appears to have two opposite effects: a harmful effect on the soil in spring, probably the result of leaching out of nitrate; and a beneficial effect on the plant as soon as it begins to grow. The net result is that both at Rothamsted and at Woburn excess of rain over the normal in March and April is distinctly harmful; one inch additional rain over the normal during the period reduces the yield at Woburn by some eight bushels per acre, the figure varying somewhat according to the fertiliser treatment. When, however, the figures are studied in relation to the time of sowing it is seen that moderate rainfall coming five or more weeks after

¹ *Zeit. Pflanz. Dung.*, 1928, 7, 314.

TABLE 13.
EFFECT OF SEASON ON YIELD. INCREASES FROM 1 CWT. SULPHATE OF AMMONIA.

	1922	1923	1924	1925	Average of	
					first four seasons 1922—1925	last five years 1928—1932
Increase in yield ..	6.5	6.6	3.7	4.2	5.2	5.4*
Yield without nitrogen ..	37.6	33.7	35.8	33.0	34.9	41.6

Omitting Woburn.

sowing is beneficial where the fertiliser treatment is sufficiently good to ensure a full crop. This accords with Hooker's examination of the Eastern Counties yields, except that he found the worst effect of rain was in January and February, while we find it is in March to May¹.

It is commonly stated by farmers in the Eastern Counties that drought in March and April is harmful to yield. Marked injury from this cause is, however, rare at Woburn in spite of the lightness of the soil, though it does occur; the best results are obtained by a rainfall of about 1.5 to 2 inches during these months.

Variations in temperature both at Woburn and in the Eastern Counties seem to have even less effect on yield than variations in rainfall.

TABLE 14.
INFLUENCE OF SEASON AND MANURING ON YIELD OF
BARLEY, *Large Scale experiments, 1922-1925 :*
all soils.
Bushels per acre.

	No Manure.	Sulphate of Ammonia			Phosph- ate and Potash only	Average
		plus Phosph- ate and Potash.	plus Phosph- ate.	plus Potash		
1922	.. 39.2	44.2	42.3	43.4	37.6	41.3
1923	.. 33.8	40.3	39.7	38.8	33.7	37.3
1924	.. 31.9	39.5	40.6	39.3	35.8	37.4
1925	.. 30.9	37.2	38.1	35.8	33.0	35.0
Average	.. 33.5	39.9	39.9	39.0	34.8	37.4

At Woburn no regularities can be detected: in the Eastern Counties Hooker calculated that high temperatures in May and June are detrimental to yield. There is no clear evidence of this at Woburn, but the effect if true could be explained on physiological grounds: high temperature hastens the change from vegetative growth to seed formation, and June is the time when vegetative growth is most active and when its curtailment would cause the greatest loss of yield².

Apparently both our average rainfall and our average temperature are rather on the high side for optimum yields of barley and something would be gained by cooler, drier seasons.

The normal range of sunshine seems to be well suited to the barley plant, especially during spring. At this time of the year barley does not seem to be very exacting; it seems to matter little to the yield whether the spring be sunny or not.

The annual variation in yield due to season is considerably greater than can be explained on any of the above effects, and further work on the subject is being continued at Rothamsted. A satisfactory explanation has still to be found for the higher yields in Ireland and the still higher yields in Scotland, than those in the Eastern Counties. The difference in liability to spring drought accounts for something as also does the coolness of the Scottish summers, but it may be doubted whether these factors explain all.

2. FACTORS AFFECTING NITROGEN (CONTENT IN GRAIN.

(a) *Soil Conditions.* The effect of soil conditions on the nitrogen content of the grain is shown in Table 16. It is less marked than on yield, nevertheless, it is very pronounced: fertilisers on the other hand have only slight influence: nitrogenous fertiliser in particular has no such action as on yield. Soil and season are about equal in their effect. The fen soil gives the barley of highest nitrogen content, as well as of highest yield, but on the other soils the nitrogen contents are in the inverse order of their yield, the chalk loam (highest yield) giving barley of lowest nitrogen content, then comes the medium loam, then the heavy loam and, finally, the sand gives lowest yields, but highest nitrogen content. This inverse relation between yield and nitrogen content commonly holds in regard to factors not involving nitrogen, such as air and water supply to the roots, soil depth, etc., but it does not hold for higher levels of nitrogen supply (Diagram 8), and hence the fen soil being rich in nitrogen falls out of line. Samples of barley from the different soils differ not only in average nitrogen content but also in the range of nitrogen content, as shown in Diagram 9. Each type tends to produce samples of a certain general character. Samples grown on the fen soils all tend to be high in nitrogen; those on the chalks to be low; and those on the loam to be higher, there being a considerable clustering about the region 1.45 to 1.65.

¹R. H. Hooker, *Quart. J. Roy. Met. Soc.*, 1922, 48, 115.

²L. R. Bishop, *this Journ.*, 1930, 352.

COMPARATIVE VARIATION IN NITROGEN CONTENT OF GRAIN ON SOILS OF DIFFERENT TYPES.

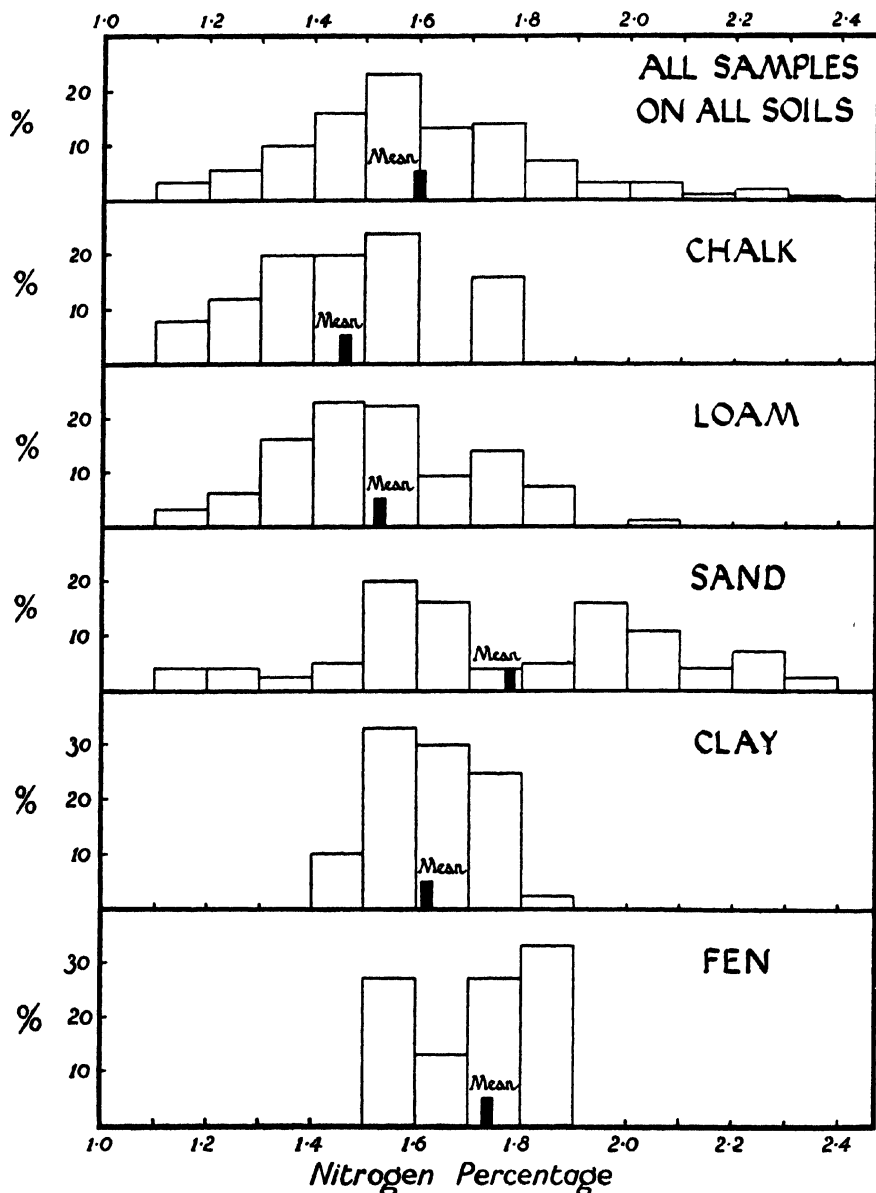


Diagram 9. This shows the percentage of the samples of barley from the different types of soil that had the nitrogen contents specified on the top and bottom lines. On the fen soil the range of nitrogen content was narrow: most samples fell between 1.9 and 1.7 and all fell between 1.9 and 1.5. On the clay the range was also narrow but the values were lower; they concentrated between 1.8 and 1.5. On the loams and chalky soils the range was wider, but the spread was towards the lower nitrogen contents: more than half the samples fell between 1.6 and 1.3, and a fair sprinkling had even lower values; only few samples however exceeded 1.8 per cent. The sandy soil showed the widest variation; it included both the highest and the lowest percentages obtained in our experiments.

The average values are shown by the small black column; the value was highest on the sands and fens. lower on the clay, still lower on the loam, and lowest on the chalky soil.

Samples grown on the sands, however, show a variability wider than on any other soil type: they may be low or they may be high in nitrogen, they are more affected by season and especially by water supply than any others. In moist conditions the yields are good and the nitrogen content low: very satisfactory samples are then obtained. In dry conditions, however, the yields are low and the nitrogen content high; it may be higher, in fact, than on the fen soils, indeed the highest nitrogen barley in the Institute series (2.28 per cent.) was grown on a light sand in Suffolk; it had been sown late and there came a drought in June (1925).

We have found no manurial scheme or cultivation device that enabled the light dry sands consistently to yield good samples.

The heavy loams on the other hand show less variation than any other soils: most of the samples fall between 1.5 and 1.7 per cent.

The effect of soil type, therefore, is to determine both the general level of the nitrogen content of the grain and the usual range of variation. The range is probably governed by the physical properties of the soil: the general level by the nature and

amount of the organic matter in the soil, particularly the ratio of carbon to nitrogen, since this determines both the amount of nitrate and the time when it is produced. A further effect of soil organic matter is to encourage late tillering and formation of small grain¹: the proportion of tail corn, therefore, shows a relation with the percentage of carbon in the soil. (Table 15.)

TABLE 15.
WEIGHT OF TAIL CORN AND CARBON PERCENTAGE IN SOIL.

Centre.	1922	1923	Carbon per cent. in soil.
	Tail Corn lb. per acre.	Tail Corn lb. per acre.	
Rothamsted	180	74	1.3
Woburn ..	60	9	1.3
Wellingore	76	163	1.87
Cawkcwll ..	150	39	2.42
Walcott ..	331	440	9.03
Eye ..	747	—	—*

* Of the same order as Walcott.

(b) *Season.* The Institute's experiments by themselves would not have sufficed to

¹ This *Journ.*, 1930, 352.

TABLE 16.
EFFECT OF SOIL TYPE AND OF SEASON ON NITROGEN PERCENTAGE IN BARLEY GRAIN.
Institute of Brewing Series.

I. Soil type—Average four years, 1922-1925.								
				Sulphate of Ammonia.			Phosphate and Potash only.	Average
				No Manure.	Plus phosphate and potash.	Plus phosphate.			Plus Potash.
Clay	1.65	1.60	1.62	1.62	1.62	1.62	1.62	
Loam	1.51	1.53	1.57	1.54	1.50	1.53	1.53	
Sand	1.77	1.79	1.82	1.77	1.75	1.78	1.78	
Fen	1.72	1.76	1.74	1.74	1.68	1.73	1.73	
Chalk	1.47	1.44	1.50	1.48	1.43	1.46	1.46	
All soils	1.59	1.60	1.63	1.61	1.57	1.60	1.60	

II. Effect of Season. Average of all Soils.								
				Sulphate of Ammonia.			Phosphate and Potash only.	Average
				No Manure.	Plus phosphate and potash.	Plus phosphate.			Plus Potash.
1922	1.66	1.73	1.74	1.71	1.67	1.70	1.70	
1923	1.67	1.63	1.66	1.68	1.62	1.65	1.65	
1924	1.46	1.42	1.46	1.43	1.43	1.44	1.44	
1925	1.59	1.65	1.68	1.64	1.58	1.63	1.63	

TABLE 17.

COMPARISON OF EFFECTS OF MANURING AND OF SEASON ON YIELD AND NITROGEN CONTENT OF BARLEY GRAIN.
Stackyard Field Light Soil Woburn.

	Yield, bushels per acre.			Nitrogen per cent. in grain.		
	Average bushels.	Annual Variation, bushels.	Per cent.	Average.	Annual Variation.	Per cent.
Unmanured	18.5	± 9.1	49	1.82	± 0.18	10
Minerals only, no nitrogen	18.3	± 7.1	39	1.74	± 0.21	12
Nitrate of Soda only	31.3	± 11.8	38	2.05	± 0.25	12
Minerals + Nitrate of Soda	40.8	± 10.7	26	1.84	± 0.27	15
Farmyard Manure	38.4	± 10.1	26	1.83	± 0.22	12

TABLE 18.

PREDICTION OF NITROGEN CONTENT OF WOBURN
 BARLEY GRAIN USING THE ROTHAMSTED FORMULA.

Year.	Predicted at end of June.	Predicted at end of August.	Found.
1885 ..	1.72	1.80	1.73
1887 ..	1.84	1.90	1.81
1888 ..	1.91	1.84	1.81
1889 ..	1.68	1.68	1.67
1890 ..	2.00	1.93	1.85
1891 ..	1.76	1.73	1.93
1892 ..	1.88	1.82	1.66
1894 ..	1.73	1.67	1.73
1895 ..	2.26	2.29	2.38
1897 ..	1.94	2.04	1.90
1898 ..	1.67	1.82*	1.56
1899 ..	1.86	1.88	1.87
1900 ..	1.84	1.92	1.99
1901 ..	2.10	2.13	2.36
1902 ..	1.62	1.71	1.63
1903 ..	1.27	1.34	1.60
1904 ..	1.95	1.95	1.83
1905 ..	1.73	1.74	2.10
1906 ..	1.72	1.79	1.72
1907 ..	1.63	1.66	1.52
1908 ..	1.89*	1.77	1.64
1909 ..	1.54	1.55	1.68
1910 ..	1.79*	1.73*	1.49
1911 ..	2.03	2.10	2.51
1912 ..	1.72	1.83	1.78
1913 ..	1.96	1.94	1.89
1914 ..	2.00	1.95	2.00
1915 ..	2.10	1.95	2.00
1916 ..	1.91*	1.82	1.68
1917 ..	1.79	1.78	1.73
1918 ..	1.96*	1.82*	1.53
1919 ..	2.12*	2.02	1.84
1920 ..	1.78*	1.67	1.59
1921 ..	2.17	2.25	2.44
1922 ..	1.95*	1.87*	1.65
1923 ..	2.11	2.06	2.07
1924 ..	1.10	1.09	1.44
1925 ..	2.09	2.14	2.29
1926 ..	1.58	1.58	1.96

Prediction too low marked -
 " " high " *

give information about the effect of season on nitrogen content of grain because they have not continued long enough. The Rothamsted and Woburn experiments, however, have gone on for a sufficient period to give the general rules.

Rainfall. The Woburn data have been examined in detail by Miss Webster, who finds that February and March rainfall tends slightly to raise the nitrogen content (due presumably to bad tilth or delays in the sowing date, see p. 329), but April and May rainfall markedly depress the nitrogen content: indeed one inch of rain above the average in May takes off on the average 0.15 per cent. of nitrogen from the barley grown on the permanent plots. The effect is so strong that the nitrogen content of the grain can be predicted with fair accuracy simply from a knowledge of the rainfall to the end of June. (Table 18). July rainfall has but little effect. At Rothamsted April rain is most potent in depressing nitrogen content. A. R. Clapham found a significant correlation (-0.54) for this month, but only a non-significant correlation with May rainfall.

The effect of spring rainfall so heavily dominates the percentage of nitrogen in the grain that it comes out clearly in the short series (7 years) of the Institute of Brewing experiments at Woburn.

At Wellngore, a light soil on the Lincoln Heath, the same general result is obtained except that the important months appear to be May and June rather than April and May. Rainfall above the normal during these two months depresses the nitrogen content at a rate corresponding to 0.05 per cent. for each inch of rain in excess. The regression equations are:—

for Wellington $N = 1.48 - 0.0616(R - 3.39)$

(39 per cent. accounted for).

for Woburn $N = 1.67 - 0.1095(R - 3.84)$

(58 per cent. accounted for).

where N = nitrogen percentage and R = rainfall in inches during May and June.

Similar results were obtained in the experiments at Martlesham and Chiselborough. At all of these centres, and in all probability, on most of the medium and light loams, this spring rainfall is the dominant seasonal factor determining the nitrogen content of the grain.

The reason for this close relationship is probably that high rainfall in spring, by washing out nitrates from the soil, diminishes the likelihood of late supplies which are known to increase nitrogen content in the grain.

The effect of summer weather on nitrogen content of the grain is but small. As already mentioned the plant sends into the developing seed a stream of material in which the proportions of nitrogen and of carbohydrate change but little as the weeks go by. The proportions are largely determined by the percentage of nitrogen in the plant when grain formation begins in May or early June.

It is, however, not entirely unchanged. Favourable growth conditions in July may add something to the carbohydrate and so somewhat improve the ratio, but usually insufficiently to make any significant difference. Even in a bad year the material going into the seed contains over 50 parts of carbohydrate to 1 of nitrogen, and in order to make any great impression on this ratio the plant needs to produce a considerable amount of carbohydrate.¹

The chief effect of summer weather is on maturation and germination capacity. These have not been specifically studied by the Committee, though they obviously play an important part in determining the valuation.

Temperature. The effect of temperature is considerably less than that of rainfall, indeed it may be only a reflection of the rainfall effect. Miss Webster found at Woburn that deviations in mean temperature above or below the average seem to be without effect up to the end of May, but

increases of temperature in July raise the nitrogen content of the grain, a rise of 10° F. over six days then adds on the average 0.01 per cent. of nitrogen.

(c) **Fertilisers.** The classical Hoosfield experiments at Rothamsted long ago settled the general principles underlying the manuring of barley and showed the three main essential elements to be nitrogen, potassium and phosphorus. The investigations of Munro and Beaven showed how the various types of manuring then tested influenced the composition and malting value of the grain and emphasised the fact, already discovered by Gilbert,¹ that manuring has less effect than season.

The results obtained in the Institute's experiments are given in Table 20.

On Hoosfield the unmanured barley has the lowest nitrogen content and lowest yield per acre. Potassic fertiliser alone, or phosphate alone, gives grain of equally low nitrogen content with the unmanured, while the phosphate gives a better yield. The only yields of commercial interest are given by nitrogenous manures, but all these raise the nitrogen considerably, adding no less than 0.2 per cent. The addition to the nitrogenous fertilisers of potassic fertiliser hardly affects yield or nitrogen content, addition of phosphate considerably improves the yield but does not lower the nitrogen content to any important extent, while addition of phosphate and potash improves yield and lowers nitrogen content by 0.12 per cent. though without bringing it to the level of the unmanured. These results showed the great need for phosphate and for nitrogen, and they further showed that, once those needs are satisfied, lowering of nitrogen content is effected by the presence of sufficient potassium. The results were applied in practice by many agricultural experts somewhat as follows: for the best quality there should be either no manure or else phosphate, while potash would improve the quality. Sulphate of ammonia should not be used alone, though it could be added to the mixture of phosphate and potash, but phosphate was of great importance.

While the principles established by the Hoosfield experiments are beyond dispute,

¹ In their studies of wheat grain, F. Knowles and J. E. Watkin (*J. Agric. Sci.*, 1931, 21, 612-637) show that the ratio of carbohydrate to nitrogen in the grain continually increases and the percentage of nitrogen therefore falls, up to within about three weeks of harvest, after which no further change could be detected.

¹ *Agric. Students' Gazette*, 1886, Vol. 3 (Rothamsted Memoirs, Vol. 6, No. 8). The figures given are for phosphoric oxide and potassic oxide.

the crude application to farm practice without further experiment is not justified because of the marked difference in conditions. Further, the widespread use of the stiffer strawed Plumage-Archer and Spratt-Archer removes much of the difficulty associated with nitrogenous manuring. In general the fertilisers act in the same direction in the Institute experiments as in the Hoosfield experiments but they produce much less effect on the nitrogen content of the grain, so small indeed as to be negligible in practice. In particular nitrogenous manuring, which considerably raised the nitrogen percentage of grain in the Hoosfield experiments, hardly altered it in the Institute experiments, raising it only from 1.47 to 1.50, though exerting the full effect on the yield. The amount of extract is not affected by manuring and the valuation of the grain is usually increased.

This is true, however, only so long as about 20 lb. soluble nitrogen is added per acre in the fertiliser—the amount corresponding to 1 cwt. sulphate of ammonia per acre. Larger quantities have a more pronounced effect on the nitrogen percentage in the grain, though a less effect on yield. This is shown in the six course rotation experiment at Woburn in 1930¹—

TABLE 19.
EFFECT OF SULPHATE OF AMMONIA ON NITROGEN
CONTENT AND YIELD.

Quantity of Sulphate of Ammonia	None.	One dose.	Two doses.	Three doses.	Four doses.
Nitrogen per cent. in grain ..	1.37	1.34	1.50	1.56	1.71
Yield, bush- els per acre	27.2	37.8	36.4	41.4	46.0

The sharp difference between the effects of the first dose and of the fourth shows how much of the discussion on the "nitrogen problem" has been due to differences in conditions: on soil comparable with the unmanured plot, sulphate of ammonia would improve the yield without raising nitrogen content: while on soil comparable with the "Three dose" plot it would markedly raise the nitrogen content without much raising the yield.

Late application of the nitrogen intensified this effect, and it is quite easy by giving enough nitrogen and by giving some of it late to raise considerably the percentage of nitrogen in the grain.

These increased percentages of nitrogen brought about by heavy nitrogenous manuring cannot be reduced by applications of phosphate or potassic manures as happens in the Hoosfield experiments.¹

The discrepancy is easily explained: Hoosfield is an exhaustion experiment, and the plots without phosphate are much poorer in phosphate than any ordinary farm soil. Arranging the Institute samples according to their nitrogen content we find:—

Nothing is gained by increasing the amount of potash and phosphate in the fertiliser.

As a result of the small effect on nitrogen content of fertilisers applied in the usual amounts it is safe to manure soils normally yielding low nitrogen barley, for there is high possibility of a good increase in yield with no loss in quality: but the manuring of high nitrogen barley will not improve the malting quality as nitrogenous fertiliser usually raises the nitrogen still further and neither phosphate nor potash brings it down, nor do the fertilisers raise the yield as much as for the low nitrogen barley. These barleys would, however, normally be used for feeding, for which purpose the increased nitrogen content is an advantage.

(d) *The Differences between Nitrogen Fertilisers.*

During the early years of the Institute series there was considerable discussion among fertiliser chemists as to the form in which the nitrogen now being fixed from the air should be offered to farmers; several possibilities were being examined. Experiments were therefore made to see whether any of the proposed compounds would have any special advantage so far as barley was concerned. In a number of the trials muriate of ammonia came out better than the old sulphate, giving higher yields of lower nitrogen content, but over the whole range of tests with other crops it had no sufficient

¹ It will be shown later (p. 328) that superphosphate has a more marked effect in lowering the nitrogen content when the barley is sown in rows wider than usual.

¹ Each dose supplied 0.2 cwt. of nitrogen.

TABLE 20.
PROPERTIES OF BARLEY GRAIN AS AFFECTED BY MANURING.
(Average of samples).

Large scale series of Institute Experiments. 1922-25.					
	No fertiliser.	Sulphate of Ammonia.			Phosphate and Potash only
		Plus Phosphate	Plus Potash	Plus Phosphate and Potash	
Nitrogen per cent in grain	1 59	1 63	1 61	1 60	1 57
1,000 corn weight	—	39 1	39 2	39 3	39 6
Valuation in shillings (per quarter) ..	52 3	53 3	53 8	53 5	53 1
Yield, bushels per acre	33 5	40 1	39 1	40 1	34 9
Valuation in shillings per acre	219 4	266 9	263 0	268 0	231 6

Nitrogen per cent. in grain

	No Manure.	Potash only.	Phosphate only.	Nitrogen only.	Sulphate of Ammonia.			Phosphate and Potash only.
					Plus Phosphate	Plus Potash.	Plus Phosphate and Potash	
1st series ..	1 59	—	—	—	1 63	1 61	1 60	1 57
2nd series ..	1 47	1 46	1 44	1 50	1 51	1 47	1 47	1 46
Hoosfield ¹ ..	1 47	1 46	1 47	1 67	1 65	1 64	1 54	1 51

¹ Average 1892—1928.*Hoosfield continuous Barley.*

	No fertiliser.	Sulphate of Ammonia only.	Sulphate of Ammonia.			Potash and Phosphate only.
			Plus Phosphate	Plus Potash.	Plus Phosphate and Potash	
Nitrogen per cent. in grain ¹	1 470	1 666	1 650	1 640	1 541	1 506
Yield, bushels per acre	13 4	23 7	35 8	25 8	39 3	19 0

¹ Average 1893—1928.

TABLE 21.
EFFECT OF FERTILISERS ON NITROGEN CONTENT AND YIELD

	Phosphate series.				Potash series.			
	Nitrogen per cent. 1 6 or less.		Nitrogen per cent. above 1 6		Nitrogen per cent. 1 6 or less.		Nitrogen per cent. above 1 6.	
	Super- phosphate	No Super- phosphate	Super- phosphate	No Super- phosphate	Sulphate of Potash	No Potash.	Sulphate of Potash.	No Potash.
Nitrogen per cent. in grain ..	1 44	1 47	1 81	1 79	1 44	1 48	1 81	1 81
Yield, bushels per acre ..	41 7	40 3	39 7	40 4	41 8	41 3	39 7	40 2

Superphosphate and Potash together.

					Nitrogen per cent. 1 6 or less.		Nitrogen per cent. above 1 6	
					Superphosphate and Potash.	None.	Superphosphate and Potash.	None.
Nitrogen per cent. in grain .. ..	..	..	..	..	1 43	1 45	1 74	1 76
Valuation .. ..	..	..	..	..	100	98		

advantage over sulphate of ammonia to justify the manufacturers in proceeding further with it. Nor were urea or cyanamide any better. The choice between these various fertilisers is, therefore, to be made on other grounds.

The final result of all the tests is that, taking sulphate of ammonia as the standard, the advantage or disadvantage of the other fertilisers used in equivalent quantity has been in bushels per acre:—

in any month. This does not mean that sunshine and meteorological conditions in other months have no effect, but that any effects are too complex to be separated out.

(c) *Fertilisers.* Nitrogenous fertilisers tend slightly to lower the 1,000 corn weight, showing that the increased yields given by the fertiliser are due to corresponding increases in the number of grains per acre. This has been confirmed by direct countings.

(d) *Relation between 1,000 Corn Weight and*

TABLE 22.

EFFECT OF DIFFERENT NITROGENOUS FERTILISERS COMPARED WITH THAT OF SULPHATE OF AMMONIA.

	Single Dressing.		Double Dressing.	
	Yield. Bushels per acre.	Nitrogen, per cent.	Yield. Bushels per acre.	Nitrogen, per cent.
Muriate of Ammonia	+ 1.4	—0.033 ¹	+ 3.6	—0.01
Nitrate of Soda	+ 1.2 ²	+ 0.035	—	—
Cyanamide	— 0.5	Nil.	— 0.15	—0.03
Urea	— 0.9	—0.01	+ 2.6	—0.01

¹ Omitting Woburn in 1925.

² Not significant.

3. FACTORS AFFECTING THE 1,000 CORN WEIGHT.

(a) *Soil.* The average 1,000 corn weight in the first five years was 39.7 grams, the extreme range being from 30.6 at Sprowston in 1925 to 48.2 at Eyton in 1922. In later years the average was lower, being 36.0 grams. Like the nitrogen content, it has been considerably affected by the season, and only slightly affected by the manuring. In general, sands give low values and fens high values, but between chalks, loams and clays there is little difference. The results are given in Table 23.

(b) *Season.* The effect of season has been investigated from the Woburn data, which go back to 1876. Rainfall above the average in January, February and March tends to depress the 1,000 corn weight, the most significant month being February, the rainfall of which accounts for 19 per cent. of the annual variance. No relation could be traced with rainfall in other months.

Temperatures above the average in March and April tend to increase the 1,000 corn weight; 17 per cent. of the annual variance is attributable to this cause.¹ No relation could be traced with temperature changes in other months, nor with hours of sunshine

Nitrogen Content of Grain. Careful examination of the whole of the data shows no consistent relation between 1,000 corn weight and the nitrogen content of the grain even for a single variety. If grains from a particular sample are sorted in order of size, the larger ones usually contain a higher percentage of nitrogen than the smaller ones, but if different samples be compared the larger grains do not necessarily contain the larger percentage of nitrogen; indeed small grains are just as likely to contain high nitrogen percentage as large grains. In the Institute series the correlation of nitrogen content and 1,000 corn weight has in some years been positive, and in other years negative, but in five of the eight years it was insignificant. The coefficients have been:—

1924,	1928,	1927,	1926,
+ .59	+ .22	+ .05	+ .02
1925,	1922,	1923,	1929.
— .20	— .23	— .27	— .65.

In 1924 the large grain and high nitrogen percentage did go together; in 1923 and 1929

¹ The regression equations are:—February rainfall $G = 37.6 - 1.17(R - 1.5)$. March and April temperature, $G = 37.6 + 0.23(T - 102.4)$; where $G = 1,000$ corn weight; $R =$ February rainfall in inches, and $T =$ March + April; maximum temperature °F. The coefficients are significant.

TABLE 23.

EFFECT OF SOIL CONDITIONS, OF SEASON, AND OF FERTILISERS ON 1,000 CORN WEIGHT.

Average 1922-1926.

	No Fertiliser.	Sulphate of Ammonia.			Potash and Phosphate only.	Average.
		Plus Phosphate	Plus Potash.	Plus Phosphate. and Potash.		
Clay	39.5	40.0	40.2	41.0	40.6	40.3
Loam	39.5	39.9	39.7	39.9	40.0	39.8
Sand	38.6	38.8	38.8	38.2	38.8	38.5
Fen	40.3	40.5	40.1	40.7	41.2	40.6
Chalk	39.8	40.4	39.4	39.6	40.0	39.9
All Soils ..	39.4	39.7	39.6	39.7	39.9	39.7

Effect of Season and of Fertilisers on 1,000 Corn Weight. Average of all Soils.

	No Fertiliser.	Sulphate of Ammonia.			Potash and Phosphate only.	Average.
		Plus Phosphate	Plus Potash.	Plus Phosphate. and Potash.		
1822	40.9	42.0	41.4	41.4	41.7	41.5
1823	39.2	39.8	39.5	39.9	39.6	39.6
1924	38.9	38.9	39.2	39.1	39.5	39.1
1925	39.8	39.7	39.8	40.0	40.0	39.9
1926	36.4	35.8	35.2	36.0	36.8	36.0
All years ..	39.4	39.7	39.6	39.7	39.9	39.66
2nd series (1930-1932)	36.4	36.1	36.0	35.6	36.4	—

2nd Series.

Sulphate of ammonia only ..	35.9
Phosphate only	36.4
Potash only	36.9

it was the opposite ; in the remaining years there was no significant connection.

4. EFFECT OF SOIL CONDITIONS AND MANURING ON VALUATION.

The valuations in the different years are summarised in Table 24.

(a) *Soils.* Placed in order of valuation of barley, the soils are :—Loam, chalk, heavy loam, sand, fen.

Soil type influences the valuation in much the same way as it influences the nitrogen content of the grain, though the two effects are not quite the same, for, even after account is taken of the 1,000 corn weight, the chalk appears to be out of place, and the fen is lower than might be expected. None of the analytical data afford any explanation of the premium given to the samples from the loams as against those from the chalks, nor do they

TABLE 24.

EFFECT OF SOIL CONDITIONS, SEASON AND MANURING ON VALUATION.

SHILLINGS PER QUARTER OF 448 LB.

(Average 4 years, 1922-1925.)

	No Manure.	Sulphate of Ammonia.			Phosphate and Potash only.	Average.	Average per cent. of Nitrogen.
		Plus Phosphate.	Plus Potash.	Plus Phosphate and Potash.			
Clay ..	50.3	51.4	51.6	51.1	51.0	51.1	1.62
Loam ..	54.9	55.6	57.0	55.8	56.2	55.9	1.53
Sand ..	48.8	51.0	50.7	51.8	49.1	50.3	1.78
Fen ..	44.8	44.8	45.0	44.8	44.7	44.8	1.73
Chalk ..	53.7	54.0	53.6	54.2	53.7	53.8	1.46
All Soils ..	52.3	53.3	53.8	53.5	53.1	53.2	1.60

Effect of Season.

	No Manure.	Sulphate of Ammonia.			Phosphate and Potash only.	Average.
		Plus Phosphate.	Plus Potash.	Plus Phosphate and Potash.		
1922 (all soils) ..	37.6	38.3	39.3	38.4	39.2	38.6
1923 ..	45.8	47.0	46.6	46.8	47.0	46.6
1924 ..	68.7	70.2	69.7	70.5	68.3	69.5
1925 ..	53.9	54.4	54.7	54.8	54.9	54.5
All years ..	52.3	53.3	53.8	53.5	53.1	53.2

Value of Crop in Shillings per Acre : Average all Soils and all Seasons.

	No Manure.	Sulphate of Ammonia.			Phosphate and Potash only.
		Plus Phosphate.	Plus Potash.	Plus Phosphate and Potash.	
	219.4	266.9	263.0	268.0	231.6
Difference per Acre due to manuring	—	48/-	44/-	49/-	13/-

explain the very low valuation of the fen barley.

(b) *Fertilisers.*

The small but favourable effect of the manures on the valuation per quarter, and their marked effect on the valuation per acre, are clearly shown, as also is the lack of correspondence between valuation and nitrogen content.

II. Effects of Cultivation Treatments on Yield and Composition.

(a) *Place of Barley in the Rotation.* The classical method of growing barley after roots and undersowing it with clover is already passing out of use and is unlikely to come back. In the new methods the barley may be taken after almost any crop, and, on mechanised farms, after a corn crop or a fallow.

TABLE 25. EFFECT OF TREATMENT OF ROOT CROP. (SPROWSTON).

	Nitrogen per cent. in grain.				1,000 corn weight.			
	No Manure.	Sulphate of Ammonia per acre.			No Manure.	Sulphate of Ammonia per acre.		
		$\frac{1}{2}$ cwt.	1 cwt.	$1\frac{1}{2}$ cwt.		$\frac{1}{2}$ cwt.	1 cwt.	$1\frac{1}{2}$ cwt.
After sheep (Roots folded) ..	1.53	1.45	1.46	—	36.4	37.8	38.4	—
Not after sheep (Roots carted)	1.38	1.29	1.29	1.30	38.0	38.5	39.0	37.7

The Institute experiments show that the preceding crop considerably affects the yield by altering the quantity of available nitrogen in the soil, but it does not much affect nitrogen content or valuation. The highest valuations in the series were given to barleys after a fairly wide range of crops:

Year.	Place.	Preceding crop.
1922	1. Martlesham	White turnips folded.
	2. Barneyhill	Potatoes, heavily manured.
1923	1. Rothamsted	Winter oats receiving 1 cwt. Sulphate of Ammonia only.
	2. Wellngore	Sugar Beet well manured.
1924	1. Porlock	Winter oats, then turnips folded.
	2. Woburn	Winter oats, unmanured.
1925	1. Porlock	Cattle cabbage fed off.
	2. Eyton	Turnips fed off.
1926	1. Chiselborough	Wheat.
	2. Nynhead	Seeds ley fed off.

Of these ten best, three followed cereals, four followed crops fed off (three being turnips and one cabbage), two followed well manured sugar beet and potato crops, and one followed a seeds ley.

In the Sprowston experiments of 1927, however, barley grown after roots folded contained more nitrogen and had smaller 1,000 corn weight than barley on adjoining land where the roots were carted.¹

The preceding crop has, however, a great indirect effect in determining the possibility of autumn cultivation and the date of sowing which, as is shown later, is one of the chief factors governing nitrogen percentage in the grain. A root crop fed off may stay on the ground so long that a good tilth cannot be obtained and sowing is driven late, and a high nitrogen grain is obtained: on the other hand winter oats (which are cut earliest of all cereals), or a seeds ley cut for hay and then ploughed under, thus giving a bastard fallow, provide the combination of fallowing and early sowing which afford

perhaps the safest way of securing barley of low nitrogen content. Under mechanised farming these conditions are likely to be obtained as a regular thing, and there is

TABLE 26. EFFECT OF FALLOWING ON YIELD AND NITROGEN CONTENT OF BARLEY.

	No Manure. (1.0)	Complete artificials. (4 A)	Farm-yard manure.
<i>Rothamsted.</i>			
Yield before fallow, 10 year average	9.3	38.4	44.3
After fallow, 1st year	21.1	63.6	61.7
Nitrogen content before fallow, 10 year average	1.43	1.51	1.83
After fallow, 1st year	1.34	1.44	1.70
2nd year	1.55	1.63	1.69
<i>Woburn.</i>			
Yield before fallow, 10 year average	8.5	16.8	25.9
After fallow, 1st year	20.3	30.6 ¹	34.7 ¹
Nitrogen content before fallow, 10 year average	1.82	1.85	1.93
After fallow, 1st year, 1929	1.33	1.28	1.32
2nd year, 1930	1.43	1.38	1.39

Compared with other barleys grown at Woburn in 1929 and 1930 the results are:—

	No Manure.		Complete Artificials.	
	After fallow.	After previous crop.	After fallow.	After previous crop.
1929, 1st year after ..	1.33	1.88	1.37	1.84
1930, 2nd year after ..	1.43	1.37	1.38	1.50

¹ The seed was sown on April 8th and there was no obvious difference in tilth.

¹ No manure added: residues only from previous dressings.

every reason to expect that it will lead to a reduction in the percentage of nitrogen in the grain.

(b) *Effect of Fallow.* Both at Rothamsted and at Woburn barley has been grown after a bare fallow, with remarkable increases in yield and a distinctly lower nitrogen content as compared with the preceding average: the effects were better than can be produced by manure on the unfallowed land. The Rothamsted crop after the fallow responded better than usual both to nitrogen and to phosphate, but it gave no response to potash.

The data are given in Table 26.

(c) *Width of Drilling and Seeding Rates.* Variations in the ordinary width of drilling make little difference to the composition of the barley though they may affect the yield. At Sprowston¹ the effect was tried of placing the drills closer than usual. The experiment was continued for three years and, while the yield was affected, no difference in character of the grain was observed, nor did it matter whether the seed was sown at the ordinary rate of $2\frac{1}{2}$ bushels per acre or the higher rate of 4 bushels per acre:—

TABLE 27.
EFFECT OF DRILLING. (SPROWSTON).

	Close drill- ing. 3½"	Ordinary drill- ing. 7"	Rate of seeding	
			2½ bus.	4 bus.
Average three years, 1928-1930				
Nitrogen per cent. . .	1.41	1.39	1.39	1.41
1,000 corn weight . .	36.0	36.9	36.6	36.3
Yield, bushels per acre	42.6	39.5		

Where, however, the barley is sown in wide rows, it is richer in nitrogen than barley sown in the usual narrow rows. This has already been pointed out by E. S. Beaven²

¹ *J. Roy Agric. Soc.*, 1930, 91, 95.

² *This Journ.*, 1902, 542.

TABLE 28.
EFFECT OF SPACING. (HOOSFIELD).

	No Manure.	Complete artificial. 4 A	Nitrogen and Phosphate. No Potash 2 A	Nitrogen and Potash. No Phosphate 3 A	Nitrogen only. 1 A	Farmyard manure. 7-2
Wide spacing, 1930	2.19	1.70	1.85	2.23	2.38	1.89
Ordinary spacing average 1893-1928 . .	1.47	1.54	1.65	1.64	1.67	1.83

and it agrees with the high results obtained in the Hoosfield experiments in 1930—values higher than ever before recorded in this field. (Table 28.)

The effect is especially marked where no phosphate is given.

It may be attributed to the late supply of nitrogen obtained by the roots either because they have been able to grow into new soil zones or else produced as the result of late cultivations given to wide rowed crops. Where the rows are too close for this, variations in their distance apart did not affect the nitrogen content.

While, therefore, the nitrogen content can be raised by widening the drills it cannot apparently be lowered by setting them closer than usual.

(d) *Undersowing.* In an experiment at Rothamsted in 1931, undersowing with clover and with rye grass had no significant effect on the yield, and only small effect on nitrogen content of the grain, whether sulphate of ammonia was given or not.

The figures were:—

TABLE 29.
EFFECT OF UNDERSOWING. (ROTHAMSTED, 1931.)
Yield, bushels of grain per ----

	No under- sowing.	Undersowing with		
		Clover.	Rye grass.	Clover and Rye grass.
Sulphate of				
Ammonia . .	32.6	37.2	32.2	33.4
No Manure . .	31.6	32.0	31.0	30.8

Per cent. of Nitrogen in grain.

Sulphate of				
Ammonia . .	1.70	1.72	1.68	1.68
No Manure . .	1.72	1.72	1.70	1.71

The experiments are being continued in connection with the Rothamsted work on the

effects of mechanisation on soil fertility, and it will then be seen whether the apparent tendency for undersown rye grass to decrease the nitrogen content of the grain is real, and if so, whether it can be developed to any practical purpose.

(e) *Type of Cultivation.* Cultivation of the land for the root crop by the new rotary tillage methods somewhat increased the yield of the succeeding barley crop, and preparation of the barley seed bed by rotary tillage gave the same results as by the older methods. With increasing mechanisation these methods are likely to increase in importance: no adverse effect on the barley crop has yet been observed, and the greater speed of action may be an advantage in favouring early sowing.¹

(f) *Date of Sowing.*—On nitrogen percentage. Late sowing markedly raises the nitrogen content of the barley as is clearly shown in the Institute results. At Woburn a delay of 20 days has meant on the average a rise of 0.14 per cent.: even when all the farms are averaged and in spite of a certain amount of cancelling out involved in comparing eastern counties with western the rise was still 0.10 per cent.²

On Thousand Corn Weight. At Woburn no relation can be traced between sowing date and 1,000 corn weight such as comes out so clearly with nitrogen percentage in the

¹ For fuller particulars see Rothamsted Reports, 1927, 151, and 1929, 97, 98.

grain, although the harmful effect of February rainfall would suggest that there is some such action. On the heavier soil at Rothamsted the connection is clearer: late sowing lowers the 1,000 corn weight: the values for 1932 are given in Table 30.

On Yield. The late sown barley also gives lower yields and so the farmer loses both in quantity and valuation; it is also more liable to attacks of insects such as gout fly and frit fly than is the earlier sown barley.

The lateness in sowing, when not due to the difficulty of removing the preceding crop, frequently results from difficulties in the weather. Part of the deterioration of the barley may be due to this cause, but the actual shortening of the growing season is an important factor. Attempts have been made at Rothamsted to mitigate this shortening effect by applying nitrogenous and phosphatic manures alone and in combination, to see if the development of the late sown plants could be hastened so as to enable them to catch up the early sown, but so far without success. (Table 31.)

² The regression equations are:—

For all Institute centres:

$$N = 1.61 + 0.049(D - 40). \text{ Where } D = \text{No. of days after February 20th.}$$

For Woburn:

$$N = 1.84 + 0.067(D - 34). \text{ Where } D = \text{No. of days after February 26th.}$$

The effect of sowing date accounts for 15 per cent. of the annual variance at Woburn and 11 per cent. at the Institute centres.

TABLE 30.
EFFECT OF DATE OF SOWING ON THOUSAND CORN WEIGHT. ROTHAMSTED, 1932

			No fertiliser.	Sulphate of Ammonia.	Superphosphate	Sulphate of Ammonia and Superphosphate.	Mean.
Sown early	..	..	47.0	47.2	47.4	46.5	47.0
Sown late	..	..	44.4	44.2	44.4	44.7	44.4

TABLE 31.
EARLY AND LATE SOWING. ROTHAMSTED, 1932.

Plumage-Archer.		No Fertilizer	Sulphate of Ammonia.	Superphosphate.	Sulphate of Ammonia and Superphosphate.
Nitrogen per cent.	Sown early	1.70	1.68	1.67	1.70
	late	1.80	1.90	1.82	1.84
Yield, bushels per acre	Sown early	51.8	65.8	56.4	65.6
	late	46.4	50.6	50.6	52.8

(g) *Autumn Sowing.* Provided the variety stands the winter, autumn sowing results in greater yields of low nitrogen grain, otherwise the yield may be considerably reduced and the nitrogen content raised, e.g., in 1930-31. The valuation is chiefly affected by the circumstance that the winter-sown barley may be harvested under distinctly different weather conditions from the spring-sown.

The results are given in Table 32.

F. C. Hawkes records instances in Essex in 1929 and 1930,¹ where barleys sown

in early October gave 50 or 60 per cent. more value per acre than barleys sown in late April.

III.—The Effects of Variety on Yield, Composition and Valuation of Barley Grain.

During the last ten years a large number of varieties have been compared by the National Institute of Agricultural Botany (N.I.A.B.) at Cambridge, and at other centres scattered over the country. Some 500 of these barleys have been valued and analysed by the Institute of Brewing, then malted in stocking and valued, and

¹ *J. Nat. Inst. Agric. Botany*, 2, pp. 142 and 232.

TABLE 32.

NITROGEN PERCENTAGE AND VALUATION OF BARLEYS SOWN IN AUTUMN AND IN SPRING.

Plumage-Archer.								
			Autumn-sown.			Spring-sown.		
			No.	N per cent.	Valuation.	No.	N per cent.	Valuation.
1925-1926								
Sprowston	..	..	142	1.34	60/-	162c 168c 149c 154c	1.52	37/-
Long Sutton	..	..	145	1.37	65/-			
				1.36	62/-		1.44	46/-
1926-1927.								
Long Sutton	..	..	145	1.41	68/-	149c 154c 162c 168c 181c 187c	1.38	53/-
Sprowston	..	..	142	1.19	70/-			
Good Easter	..	..	188	1.35	48/-		1.41	53/-
				1.32	62/-		1.36	59/-
1929-1930.								
Good Easter	..	..	110	1.39	45/-	108	1.40	42/-
Long Sutton	..	..	115	1.45	53/-	113	1.37	49/-
				1.42	49/-		1.38	46/-
1930-1931								
Good Easter	..	..	4	1.70	25/-	8	1.31	30/-
Long Sutton	..	..	30	2.23	19/-	34	1.52	33/-
				1.96	22/-		1.42	32/-
Spratt-Archer.								
1926-1927.								
Sprowston	..	..	194	1.32	48/-	164	1.33	70/-
Good Easter	..	..	190	1.64	48/-	183	1.37	52/-
				1.48	48/-		1.35	61/-

analysed as malts. In addition, comparisons between selected varieties have been made by the Institute of Brewing on the extremely wide range of soil conditions provided by the permanent barley plots at Rothamsted and Woburn Experimental farms. The very extensive data show how different varieties respond to differences in soil and season.

The N.I.A.B. results are summarised in Table 33, all varieties being compared with Plumage-Archer (1924) taken as a standard.

Except Spratt-Archer and 35/51 all were inferior on the average to Plumage-Archer in at least one respect, either in yield, valuation, thousand corn weight, nitrogen content or extract. Most of them were inferior in several respects. The significant results are printed in heavy type.

The three varieties, Plumage-Archer, Spratt-Archer and their hybrid 35/51, emerge as the best varieties under all the conditions recorded. When grown side by side, Plumage-Archer has almost the same percentage of nitrogen as Spratt-Archer over a very wide range of soil and seasonal conditions;

but Spratt-Archer gave considerably lower thousand corn weight. The relative constancy of the differences between one variety and another in spite of the wide range of soil and seasonal conditions, suggests that one could express the differences as a varietal constant. (Diagram 10.)

Weigert and Fürst¹ obtained results which also indicate that differences shown by different varieties of barley grown side by side amount almost to physiological constants.

It thus appears probable that one could prepare a list of superior varieties, each of which would be unbeaten for a certain purpose or a certain region, though it might be equalled. The adoption of a standard variety throughout each region would probably be advantageous alike to growers, maltsters and brewers.

This persistence of the relative positions of the different varieties holds true, not only for normal agricultural soils, but also for extreme conditions. This important point

¹ Weigert and Fürst, *Zeit. Pflanz. Düng.*, 1929, 369.

VARIETAL DIFFERENCE OR SIMILARITY AND ITS CONSTANCY OVER A WIDE RANGE OF CONDITIONS.

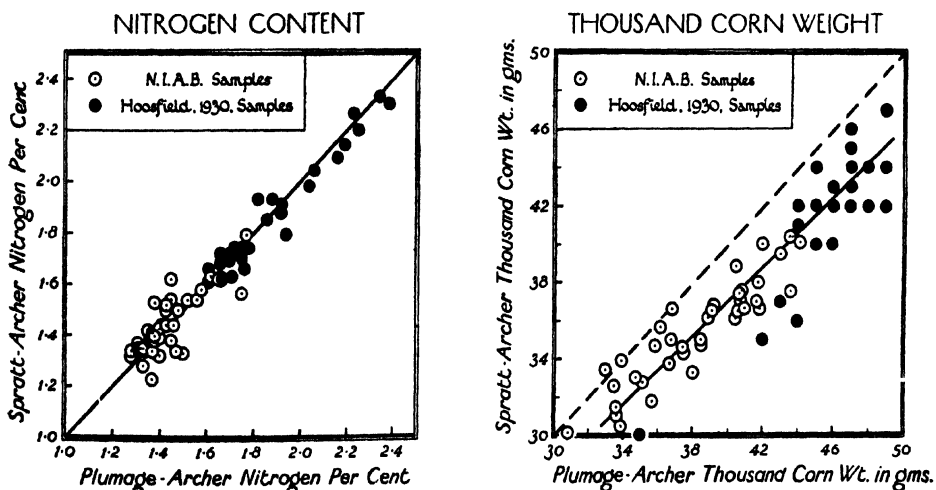


Diagram 10. This shows that Plumage-Archer and Spratt-Archer have always the same nitrogen content when grown under similar conditions. The nitrogen content of each sample of Plumage Archer is plotted horizontally, and that of the corresponding sample of Spratt-Archer is plotted vertically. If the two values were always the same, all the resulting points would fall on the diagonal line. The diagram shows that the agreement is close under a very wide range of conditions.

The points for the 1,000 corn weight, on the other hand, do not fall on the diagonal line, but on a line nearly parallel to it and lying below it. The difference is about 3 grams in favour of Plumage-Archer, which always has the higher 1,000 corn weight when grown under the same conditions. The difference is not quite constant, and it appears to be slightly less at low values than at high ones.

was tested both at Rothamsted (Hoosfield) and at Woburn (Stackyard Field), where two varieties were grown side by side in half drill strips (Beaven method) on plots which represented extreme deficiencies of various elements. At Rothamsted, Spratt-Archer was compared with Plumage-Archer; its yield was about 15 per cent. higher under all conditions, excepting only of potash starvation, when the two were about equal. At Woburn, Archer was compared with Plumage; it was superior under all conditions both of starvation and of full nutrition (Table 34). Even under these extreme conditions there was no evidence of differences in behaviour according as the varieties are grown under starved or normal conditions, such as are recorded in the pot cultures of F. G. Gregory².

The results indicate that soil starvation conditions could be met to some extent by suitable choice of varieties, but in practice it is more effective to seek a remedy in suitable manuring.

Until recently the improvement in extract has been obtained by reduction of nitrogen

content, and a number of brewers and brewers' chemists maintain that the process has gone too far, and that some of the modern barleys contain too little nitrogen for the satisfactory production of modern light beers.

Some varieties, however, contain more nitrogen than Plumage-Archer, and yet give as much or nearly as much extract, e.g., Standwell, Golden Pheasant and 59/120, 824 and 825. The first three give poor yields, but the two latter give high yields, and may prove of value.

This question of yield is of great importance because no variety of barley is likely to commend itself to growers unless it yields well. The results given in Table 33, and illustrated in Diagram 11, show that low nitrogen content is an inevitable accompaniment of high yields. There is, in fact, a fairly close relation between yield and nitrogen content, indicating that different varieties generally take up the same quantity of nitrogen from a given soil, but some use the nitrogen more efficiently than others, producing a larger amount of carbohydrate and, therefore, necessarily bearing grain of lower nitrogen content. Plumage-Archer

TABLE 33.

COMPARISONS OF DIFFERENT VARIETIES WITH PLUMAGE-ARCHER (1924).

Variety.	n	Yield Plumage-Archer = 100%.	Valuation in Shillings.	Nitrogen, per cent.	1,000 Corn Weight.	Extract on raw barley.
Cambridge						
59/120	11	+ 0.0 ± 4.3	—	+ 0.12 ± 0.04	— 3.3 ± 0.8	+ 0.5 ± 1.2
Archer ..	8	— 5.5 ± 1.8	—	+ 0.11 ± 0.02	— 3.1 ± 0.8	— 3.0 ± 0.9
Beaven's						
Archer	16	+ 0.1 ± 1.4	— 4.4 ± 0.9	+ 0.04 ± 0.01	— 2.2 ± 0.5	— 0.7 ± 0.5
Golden						
Pheasant	10	— 16.9 ± 2.2	—	+ 0.16 ± 0.02	— 2.6 ± 1.0	— 0.7 ± 0.4
Gartons 1917	6	— 8.1 ± 4.3	—	+ 0.13 ± 0.03	— 2.8 ± 0.6	— 3.6 ± 0.9
† Webb's						
Sunrise	27	+ 1.0 ± 1.9	— 5.3 ± 1.1	+ 0.04 ± 0.01	— 1.3 ± 0.4	— 0.7 ± 0.3
Archer-						
Goldthorpe	14	— 9.0 ± 2.1	— 1.8 ± 0.9	+ 0.01 ± 0.02	+ 0.7 ± 0.5	+ 0.5 ± 0.3
Beaven's 25 ..	15	— 2.8 ± 1.9	— 0.9 ± 0.4	+ 0.06 ± 0.02	+ 1.2 ± 0.4	— 0.4 ± 0.5
Plumage ..	9	—	+ 1.4 ± 2.3	+ 0.03 ± 0.05	+ 2.7 ± 1.0	—
Goldthorpe ..	9	—	+ 0.3 ± 1.6	+ 0.05 ± 0.05	+ 2.5 ± 0.6	—
Chevallier ..	9	—	+ 2.3 ± 1.5	+ 0.11 ± 0.04	— 0.6 ± 0.8	—
* 35/51 ..	12	+ 14.7 ± 5.7	+ 2.4 ± 1.0	+ 0.03 ± 0.02	— 2.2 ± 0.5	+ 0.1 ± 0.5
824 ..	28	+ 1.0 ± 1.0	— 2.5 ± 0.6	+ 0.09 ± 0.01	— 1.6 ± 0.2	— 0.1 ± 0.3
825 ..	28	+ 2.1 ± 0.9	— 2.0 ± 0.5	+ 0.05 ± 0.01	— 2.3 ± 0.3	+ 0.1 ± 0.2
Standwell ..	7	— 14.2 ± 9.1 ³	— 8.0 ± 3.7	+ 0.29 ± 0.07	+ 4.7 ± 1.9	— 1.7 ± 1.2
Spratt-Archer	44	+ 7.2 ± 1.5	— 0.9 ± 0.4	+ 0.005 ± 0.011	— 2.8 ± 0.2	+ 0.2 ± 0.2

* Closely similar to, if not identical with, Beaven's Golden Archer.

† = Webb's B. Plumage-Archer 1924 = Beaven's 1920.

³ From three comparisons only. The corresponding nitrogen average is used in Diagram 11.

TABLE 34.

COMPARISON OF SPRATT-ARCHER AND PLUMAGE-ARCHER at Hoosfield, Rotherhamsted, 1929-32.

Spratt-Archer above (+) or below (—) Plumage-Archer.

Manurial Conditions.	Mean Yield. bus. per acre.	Varietal Difference. bus. per acre.	Nitrogen, per cent. ¹	1,000 corn weight, grms. ¹	Valuation.
<i>Good.</i>					
Farmyard manure, 7·2	36 8	+ 6·36	+ 0·046	— 2	Spratt-Archer slightly less
Complete artificials, 4A	32 0	+ 5·60	— 0·010	— 3	„
<i>Poor.</i>					
Nitrogen starvation, 4o	17 2	- 3·46	— 0·035	— 2	Spratt-Archer slightly less.
Potash „ 2A	30 2	— 0·80	— 0·006	— 7	No difference.
Phosphate „ 3A	9 8	+ 1·84	— 0·029	— 5	„
Complete „ 1o	7 6	+ 1·04	— 0·054	— 5	„

Standard deviation of differences in yield = $\pm 2\ 24$.

The varietal differences in yield are not significantly different amongst themselves.

¹ 1930 only.

COMPARISON OF PLUMAGE WITH ARCHER.

Stackyard Field, Woburn.

Manurial Conditions.	Yield of Plumage when Archer = 100.		<i>p_H</i> of Soil.
	1931.	1932.	
<i>Good.</i>			
Farmyard Manure, 11B	82	86	6·28
Complete Artificials—			
Sulphate of Ammonia, 5B.	76	—	6·75
Nitrate of Soda, 6.	82	84	6·23
Nitrogen starvation, 4A.	90	—	5·80
Potash „ 10A.	83	59	5·81
Phosphate „ 11A.	75	70	5·87
Complete „ 1.	69	80	5·83

and Archer-Goldthorpe are somewhat exceptional in that they produce more carbohydrate and therefore bear grain of lower nitrogen content for a given uptake of nitrogen; Plumage-Archer grain, indeed, is lowest of all in nitrogen content.

There is at present no indication that varieties combining high yield with high nitrogen content could be produced.

IV. — The Possibility of Controlling Nitrogen Content of the Grain.

The preceding sections show that it is easy to increase the nitrogen content of the grain beyond what is obtained by ordinary good cultivation and management, but difficult to decrease it at will much below this level. The distribution curve for the

nitrogen percentages in the Institute samples therefore drops steeply to the low percentage, but tails off more slowly to the high ones. (Diagram 9).

Increased nitrogen content is brought about by :

(1) Increasing beyond a certain point the supply of soluble nitrogen nutrients to the plant.

(2) Giving late supplies of nitrogen nutrients.

(3) Growing the barley on soils rich in organic matter.

(4) Dry weather during the spring months, especially April and May.

(5) Late sowing of the barley.

(6) Late cultivation of the barley or sowing in wide rows.

AVERAGE NITROGEN PERCENTAGE AND AVERAGE YIELD OF DIFFERENT VARIETIES COMPARED WITH PLUMAGE-ARCHER.

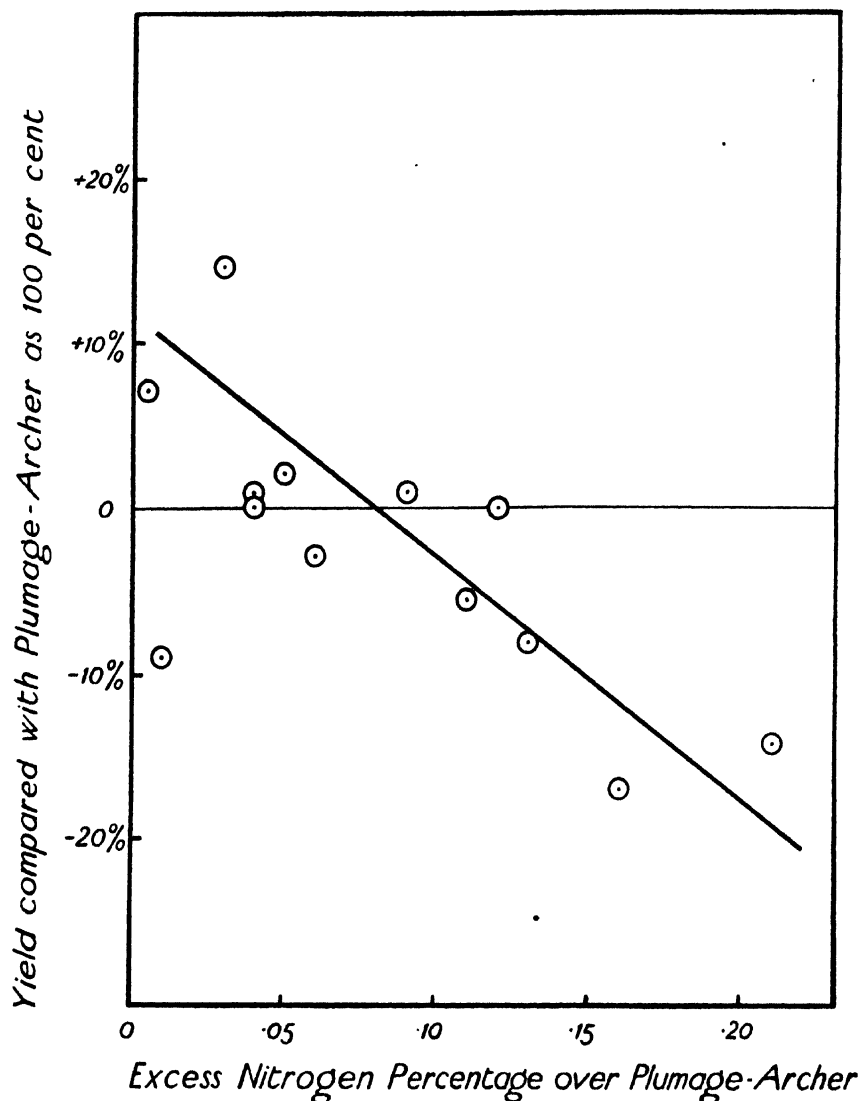


Diagram 11. This shows that varieties normally giving high yields have low nitrogen percentages, while those normally giving lower yields have higher nitrogen percentages. With two exceptions, the yield and nitrogen content are almost inversely proportional, suggesting that all the varieties have taken up the same amount of nitrogen from the soil when grown side by side, but some have been able to make more carbohydrate than others. The two exceptions are Plumage-Archer and Archer-Goldthorpe, which, for equal yields, contain less nitrogen in the grain than the others.

(7) Sowing varieties that normally contain a high percentage of nitrogen.

Decreased nitrogen content is brought about by :

(1) Wet weather during the late spring months, especially April and May.

(2) Early sowing of the barley.

(3) Growing barley after a fallow.

(4) In general any factor facilitating full growth and development of the barley.

(5) If the nitrogen content is already low it may be further lowered by dressings of phosphatic, potassic and sometimes also of nitrogenous fertiliser, but if the nitrogen content is already high (above 1.6) these fertilisers do not usually lower it.

(6) The use of varieties normally yielding grain of low nitrogen content.

Summary of factors controlling yield.

Previous treatment of land.

1. *Fallowing.* This gives the most striking improvement in yield; the increases in some of our experiments being as much as 17 bushels per acre.

2. *Previous cropping.* This is important, chiefly in so far as it affects the preparation of the seed bed, the date of sowing and the manurial residues. Crops removed early are better than those removed late, and the best results are obtained where a bastard fallow can be given.

3. *Early sowing.* A delay of one month has reduced the yield by as much as 7 bushels per acre.

4. *Choice of suitable varieties.* It is not uncommon to find that a well-chosen variety gives several bushels per acre more than the older sorts. Plumage-Archer, Spratt-Archer and Golden Archer have all proved valuable.

5. *Nitrogenous manuring.* 1 cwt. sulphate of ammonia has usually added 5 to 6 bushels per acre to the yield.

6. *Seasonal conditions.* Spring rainfall beyond a certain quantity lowers the yield; at Woburn the best results are obtained with a rainfall of 1.5 to 2 inches in March and April, while each inch above the average lowers the yield by 8 bushels per acre.

Summer rainfall is less effective.

High summer temperature is detrimental to yield.

Summary of the effects of seasonal conditions on yield and composition of barley.

The observations recorded in the preceding pages are collected here in summary form. A + sign shows an increase, ++ a stronger increase, and — signs show decreases. (Table 35).

V.—The Possibility of Forecasting Yield and Nitrogen Content of Barley.

Knowing the average yield of barley for a given region and the full effect of the various factors causing deviations from the average, it would be possible to forecast the yield with certainty. The full effects of weather conditions on yield, however, are not known and in consequence it is not yet possible to account for the whole of the deviation. At Woburn about a third of the deviation can already be accounted for, but this does not suffice for the making of predictions.

A second method of forecasting yield can be based on the fact that the fully grown plant is largely the result of what happens earlier in its life. There are grounds for expecting that a good estimate of yield could be obtained from appropriate measurements taken while the plant is growing.

TABLE 35.
SUMMARY OF WEATHER OBSERVATIONS ON YIELD AND CHARACTER OF BARLEY.

Weather compared with average.	Previous Winter.			Spring.			Summer.		
	Yield.	Nitrogen per cent.	1,000 Corn Weight.	Yield.	Nitrogen per cent.	1,000 Corn Weight.	Yield.	Nitrogen per cent.	1,000 Corn Weight.
Rainfall—Higher ..	— ¹		—(Feb.)	—	—		+	+	
Lower ..	+ ¹		++	—	++				
Temperature—Higher						++	— ¹	+	
Lower						—	+ ¹	—	

¹Hooker for Eastern Counties : not at Woburn. Where no signs are given no relationship could be traced.

The effects of weather conditions on the nitrogen content of the barley grain are, however, more readily stated than the effects on the yield, and, as their operation is much more marked in the early period of growth than in the later, it becomes possible to calculate the nitrogen content of the grain, and along with it the associated properties, amount of extract, diastase, etc. The figures can be available at the end of June while the crop is still standing and before any samples have been taken for analysis. Up to the present over 80 predictions have been made, and in 75 per cent. of the cases the discrepancy between the predicted and the subsequent actual percentage has been less than 0.1 per cent. There are discrepancies in the high nitrogen group, but these are of less importance, as the maltster is not usually interested in this group in any case. The method of prediction is fully explained in a forthcoming paper. Further improvements in the prediction can be expected by introducing terms allowing for date of sowing and weather conditions other than late spring and early summer rainfall. Some of the results are given in Table 18 (p. 320).

A prediction formula for nitrogen content also based on rainfall relationships has, we understand, been worked out in the Statistical Department of Messrs. Arthur Guinness & Son, and successfully applied to barleys grown in Cork. The general relationship is similar to ours, but the critical times are different: the beneficial effect comes in April and May, instead of February and March, and again in July instead of August. In June there is no actual depression but merely a lack of effect. A close comparison of the two methods would be of great interest and value, but the details of the Dublin investigation have not been published. A second method of predicting nitrogen content is being investigated: it is based on the fact that during the development of the grain the carbohydrates and the nitrogen compounds pass in together. Their relative proportions depend on the composition of the plant at the time when the filling of the grain is proceeding actively. The nitrogen content of the young developing grain estimated in July is sensibly the same as that of the fully ripe grain.

SECTION VI.

Agricultural Recommendations.

In the preceding pages the factors determining yield and quality of barley are set out, and also the magnitude of the effect which any particular factor is likely to exert. Knowing these things the agricultural expert can advise farmers in any particular district whether they may expect high or low yields and whether their methods are likely to give grain of high or low nitrogen content. The valuation is however much affected by harvest conditions. The farming conditions of Great Britain are so varied that it is not possible to lay down general rules that will apply everywhere, but we can summarise the agricultural material so as to bring together the various conclusions of direct interest to the grower.

At the outset, it must be emphasised that the demand for malting barley is limited. Agriculturists must not suppose that by learning to grow malting barley, they will necessarily be able to sell it at a high price. Even before the recent fall in the consumption of beer the amount of barley used in British beer was little more than three million quarters per annum, and only between two-thirds and three-fourths of this (largely dependent on harvest conditions) was bought from English growers. There remains always the hope and the possibility that a good deal of the remainder could be grown here also, and indeed none of the laboratory investigations yet made has shown anything in the character of the extract obtainable from imported foreign barleys that English barleys lack in good seasons. Most practical brewers maintain, however, that they cannot obtain the results they want without a proportion of the more husky six rowed-barley to assist drainage in the mash tun and it is for the research worker to discover whether such barleys cannot be economically produced here so as to satisfy all requirements. This work is still going on. Agriculturists should also remember in comparing the relative demands for English and for Californian barley that Californian barley contains much less water than ours—only about 10 to 12 per cent. as against 15 per cent. in a good year and 18 per cent. in a bad year for English barleys. In consequence Californian barley not only yields some 6 or 7 per cent. more malt per quarter than ours, but being drier it can be held in store at the

docks or elsewhere for two years without any treatment not only without deterioration, but with frequent improvement; while British barley usually has to be kiln dried, which is a further expense and trouble.

Meanwhile, in view of the restricted demand, it is only courting disappointment to attempt anything like over-production of malting barley.

The chief factors in determining quality are the soil and the weather. Certain fields will nearly always produce good malting barleys (harvest being favourable), others only rarely do so. Medium to light loams are the most trustworthy soils, heavy loams and sands come next, and fen soils and clays are the least likely to give good samples. Of all these soils the sandy ones are the most speculative; our best and our worst samples have come from them.

It follows that farmers on any excepting the medium and light loams should not be advised to put much faith in their prospects of selling their barley to the maltster and while the present low demand continues.

Starting then on a medium or light loam, the first thing to settle is the variety. A large number have been tested, but Plumage-Archer and Spratt-Archer still remain the best, giving about 5 to 10 per cent. more yield than others; Plumage-Archer yields slightly less, but its 1,000 corn weight is better, and its average valuation is slightly above that of Spratt-Archer.

In regard to cultivation: fallow has in our experiments been the best previous treatment of the land both for yield and quality. In practice a dead fallow would be out of the question, except on a mechanised grain farm, but early autumn cultivation would be the next best thing. This could be given after a preceding grain crop or after a seeds ley. What form the cultivation should take must of course be determined by the actual conditions of the farm, but it should give as nearly as is possible the effects of a bastard fallow. Barley will not tolerate acidity of the soil, and the Woburn experiments show that it suffers more easily from this cause than any of the other cereals. The first sign of acidity is patchiness in the crop; the root crops and clover also tell the tale to those who can read it; swedes get finger and toe, and mangolds and sugar beet fail to grow up; they start into growth but do not develop. Clover

dies in patches during winter. If the crops show these signs lime should be added to the soil; the County Organiser can arrange for a test to be made to show what would be a suitable quantity to add.

The sowing of the barley should be as early as is practicable consistent with the getting of a good tilth and the likelihood of steady continuous growth afterwards. It is very important that the plant should suffer no check once it has started growing and the sowing date must be so chosen that the barley can grow steadily on without being held up by a long spell of bad weather. In the Southern and Eastern Counties, February or early March is the time at which to aim, but elsewhere later times may be better. This is one of the most important items in the spring management and it is one reason why barley after roots folded to sheep is often less satisfactory in quality than barley after a corn crop. Whenever the folding has thrown the sowing late it prejudices the quality; further, it is often difficult to get the land into good condition after folding.

Autumn sowing sometimes gives even better results than early spring sowing, but one cannot rely on this. As yet no two-rowed winter variety is entirely hardy, and although in favourable conditions the result is successful—in Essex autumn sown Plumage-Archer barley has in some cases given a 50 per cent. better cash return than spring sowing—nevertheless, the risk of failure is always there. Search is still being made for good reliable winter varieties including good six-rowed sorts that might replace the imported six-rowed barleys.

Coming back to sowing: the rate of seeding is not very important and $2\frac{1}{2}$ bushels per acre usually gives as good a result as any other. The drills, however, should not be too wide: the usual 7 inches between the rows is quite wide enough: indeed somewhat better yields, and equally good quality, were obtained at Sprowston by setting the drills only 4 inches apart. Widening the rows much beyond the usual width, however, had the effect of raising the nitrogen content of the grain which is undesirable.

Manuring if properly carried out raises the yield without injuring the quality; indeed it improves the valuation set on the grain by the buyer. The most important constituent is nitrogen, and the most useful

quantity to add is 20 lb. per acre ; this corresponds to 1 cwt. sulphate of ammonia or $1\frac{1}{4}$ cwt. nitrate of soda given at the time of seeding. It used to be thought that nitrogenous manuring would injure the quality of the grain, and both agricultural experts and maltsters have in the past advised against it. There may have been some cause for anxiety in the old days with the old varieties, but with Plumage-Archer and Spratt-Archer there is little to fear, they stand up to this quantity of manure and they commonly give in return an additional 5 or 6 bushels of grain with no loss of quality whatsoever. It is, of course, imperative that the barley should not be lodged and a farmer who fears that this might happen must refrain from adding sulphate of ammonia to barley on land in very high condition. As between one nitrogenous manure and another there is little to choose ; price and convenience in use are the deciding factors, phosphatic and potassic manures, on the other hand, are more specialised in their value. There are many soils on which neither acts for barley, but on the other soils they are needed. At the Norfolk centres superphosphate gave profitable increases in yield ; at many of the other centres it did not. Barley needs phosphate more than wheat does, but the need for phosphate has hitherto been met by the large dressings given to the root crop which preceded it. With the reduction in the acreage under roots, however, these dressings will no longer be given and then the need for supplying phosphate to the barley will become greater. Potassic fertilisers were effective on the light soils but not on others.

In the harvesting and after treatment of the crop it is of great importance to secure grain as dry as possible and of high germination capacity. Recently artificial drying of the grain has been practised on some farms ; this is at present risky because the process cannot be fully controlled, and an excess of temperature may badly injure germination. At the same time the process is a very promising subject for investigation, and if it could be so worked as to cause no complications for the maltsters it would undoubtedly be a great advantage to the grower.

Effect of Season.—The most important factors for the barley crop are the weather before sowing ; the rainfall during March,

April, May and June ; the temperature during July ; and (more important than either), the weather at harvest time.

The weather just before sowing determines the state of the seed bed and the date of sowing, and late sowing reduces yield, lowers the 1000 corn weight and raises nitrogen content. Rainfall during March and April lowers yield considerably if it much exceeds the usual quantity, but drought during this period is also harmful. Rainfall during April, May and June lowers the nitrogen content of the grain and so tends to improve the valuation ; on the other hand drought during this period raises the nitrogen content and tends to lower the valuation. Temperatures above the average in July lower the yield and slightly raise the nitrogen content.

Thus by the end of June the farmer should have a very fair idea of whether his barley is likely to be higher or lower in nitrogen than usual. If sowing has been delayed, if April, May and June have been drier than usual, other things being equal, this may easily mean a lower valuation, unless indeed the harvest conditions are so good that his sample looks attractive in spite of its high nitrogen content. On the other hand if the barley were sown early and went in well ; if April, May and June have been moister than usual, the grain will contain less nitrogen than usual and so offers the possibility of making good malting barley.

It is, however, the conditions of harvesting that finally determine whether or not a crop of barley is either choice, or passable, or impossible malting material.

No pale ale brewer will buy " weathered " barley or malt made from it and no brewer or maltster will buy any barley if its germinating capacity has been injured by either adverse weather during harvest or by the after effects of stacking—always more serious when harvesting conditions are adverse.

When a large part of the home crop is injured as happens in exceptionally wet harvest seasons, maltsters and brewers naturally purchase a larger proportion of barley coming from those countries where the harvest weather was better than in this country.

VI.—General Summary : the Progress of the last ten years.

Fortunately for us the barley problem as it stood ten years ago was summed up by H. F. E. Hulton¹, so that it is possible to set out the progress made as a result of the Institute investigations.

Mr. Hulton emphasises the uncertainty and inconsistency of much of what he then recorded. "Any attempt to sum up the mass of facts and opinions might well appear a rather desperate task," he says. To a large extent this arises from the circumstance that barley is a living thing, and, like all other living things, liable to a certain amount of variation according to the conditions.

Trustworthiness of experimental results.

Perhaps the most important advance recorded in the preceding pages is that, thanks to the large number of experiments made, and the care taken to ensure that the results should be strictly comparable, it is now possible to state what degree of trustworthiness attaches to the various results. No statement about barley is likely to be always true, but it may be true nine times out of ten and so be near enough for ordinary practical purposes : yet if it breaks down on the tenth occasion it may quite legitimately give rise to considerable controversy, which, however, falls into its proper perspective when it is known that the exception occurs only once in ten times. The advantage of the statistical treatment adopted in these investigations is that each result can be tested to find out the probability that it is really due to the cause to which it is attributed ; usually a result has been passed as "significant" if the odds were about 20 to 1 against it being due to anything else. In many instances also it has been possible to state approximately what percentage of the effect can be attributed to a given cause so that we know roughly how much still has to be accounted for : and in a few instances we have been able to account for nearly all the result.

Primarily, the purpose of the research was to obtain knowledge of the barley grain, and this test of the trustworthiness of the knowledge was, of course, essential. It can be used in two ways in practice : either to control a process or to predict what will

happen. We have shown that prediction is often possible where control is not.

Nitrogen compounds in barley grain.

No part of the subject was in a more confused state than the relationship of the nitrogen compounds in the barley grain to the extract of the malt. Mr. Hulton summarised the situation very simply ; he records that 50 per cent. of the workers think there is a connection between nitrogen content and extract, 36 per cent. are doubtful, and 14 per cent. are sure there is none. This part of the subject has been satisfactorily cleared up ; it is shown that a close relationship exists not only between the nitrogen content and the extract but also between the total nitrogen and the amounts of the various nitrogen compounds. The work has been done quantitatively, and a method has been worked out for predicting the extract in the malt from the nitrogen content of the grain and its thousand corn weight. The method has been widely tested in practice and found to hold good ; it is now used by several large buyers in the purchase of their barley. From the point of view of the research, however, the importance of the result lies in the fact that accuracy of the prediction means correctness of the basis of the prediction, and this basis is the relationship and equations set out on p. 308.

The close connection between the amounts of the individual proteins and the total nitrogen, expressed by the curves in Fig. 1, has cleared up a difficult and involved subject. It is now shown that the quantities of hordein, glutelin and of the other nitrogen compounds are always closely related to one another and to the total nitrogen. Barleys of the Plumage-Archer type contain, at 1.35-1.5 per cent. of nitrogen, about equal proportions of hordein, glutelin and salt-soluble nitrogen compounds in the fully mature grain.¹ Barleys of lower nitrogen content contain somewhat less hordein, but barleys of higher nitrogen content contain much more,² with correspondingly

¹ *i.e.*, after about three years' storage. In immature grain the percentage of salt-soluble nitrogen is higher, and of glutelin and hordein lower, than in mature grain.

² They are, as Dr. Beaven pointed out, frequently steeley, but there is nothing to show that the steeliness is due to any special proportions of the individual proteins. An explanation based on physical properties is much more satisfactory.

¹ This *Journ.* 1922, 33.

less salt-soluble nitrogen compounds. Of all the many samples of barleys examined, none has ever been found to contain an abnormal proportion of hordein or of glutelin; the relations seem to hold invariably, and to be definite characters of the variety. Similar regular relations apparently occur between the carbohydrates in the grain.

Distinctiveness of Varieties.

The result set out in the preceding paragraph is of great scientific value as showing that each variety of barley is built up on a definite pattern, which can be altered by changes in conditions, but only within the limits set by the pattern, so that the variety always retains its distinctive character. It is therefore possible from a determination of the percentage of nitrogen to state at once the whole composition of the grain as we know it at present.

Different varieties have different patterns, and the differences are more marked among the six-rowed than among the two-rowed varieties, but in no conditions so far discovered do the patterns merge or lose their distinctiveness. The differences between different varieties constantly re-appear in all the tests made under normal agricultural conditions, though there are some reversals of effects under conditions of abnormal starvation. The character of the pattern can by plant breeding methods be changed within limits defined by the laws of genetics; within these limits new varieties having different proportions of the various nitrogen compounds and carbohydrates can be produced. Some of these varieties may be better suited than existing sorts to the special requirements of different groups of maltsters and brewers. There seems, however, to be no necessity for a large number of varieties, and it would probably be to the advantage of all concerned if growers, maltsters and brewers could agree to concentrate on a few standard sorts. Plumage-Archer and Spratt-Archer are distinctly superior to others in yield, valuation, low nitrogen content and high extract.

Changes in Nitrogen compounds during malting.

It is almost certain that the changes in the nitrogen compounds during malting proceed in two opposite directions. The proteins in the seed (endosperm) are broken down to simpler compounds, but some of these are

again built up into complex proteins by the germinating plantlet. Thus the amount of the simpler compounds finally appearing is not a complete measure of the total change, nor are the final proteins merely the residual proteins of the original grain. Nevertheless, the nitrogen compounds of the malt and wort show regular relations with those of the grain.

For any given variety it is possible, from the nitrogen content of the grain, to calculate not only the quantities of the various proteins in the barley, but also the quantities of the various groups of nitrogen compounds in the malt and in the wort.

These close relationships are of great importance for future researches into the influence of proteins in brewing, as they set definite limits to a group of problems that might otherwise be too vague to permit of adequate investigation. Again, one great value of the correctness of the predictions is that it proves the correctness of the relations.

Relation of barley composition to malting and brewing uses.

The method of working adopted by the Committee had the advantage of providing a great number of barley samples of known history and controlled origin. These were fully analysed, malted, and valued, and the resulting data were statistically analysed, first to test their trustworthiness, and then to see what information they could be made to yield.

The valuations put the barleys into seven grades, and the analysis shows that, on the average, the customary methods, especially the nitrogen determination, placed the barleys in their proper grades, excepting only the first, where no analytical method held good. In passing from the 1st to the 7th grade, not only did the quantity of extract fall off, but also the payment per lb. of extract.

The brewing tests made up to the present have been insufficient to settle the very important problem of the brewing value of the barleys in these various grades. The experiments so far indicate that extracts from barleys containing moderately high (1.6-1.7) percentage of nitrogen yield beers that taste better at first than those made from low nitrogen barleys, but on storage the flavour deteriorates, while that of beer

from low nitrogen barley improves. Barleys of moderately high nitrogen content are, therefore, best for beers made for immediate consumption, while those lower in nitrogen are best for beers intended for storage. No evidence could be found for the old view associating high nitrogen barleys with haze in the finished beer : but it does seem that low nitrogen barleys have certain special yeast relations.

Importance of nitrogen content of grain.

The laboratory work having emphasised the prime importance of nitrogen content in the grain, the field work set out to discover how this is related to soil, season, manuring and other conditions. Ten years ago, as shown by Hulton, the nitrogen content of the barley was supposed to be determined largely by the conditions in the later part of the plant's life ; it was associated with the maturation ; too rapid or delayed maturation was supposed to lead to high nitrogen content, and *vice versa*. There was also considerable uncertainty as to the effects of other factors, especially of manures and of weather conditions.

The Institute results have cleared up the situation considerably. They show that the nitrogen content of the grain is determined in the earlier part, and not in the later part of the plant's life, and that it is hardly affected by the maturation processes. Maturation of course still remains an outstanding factor in determining malting value, probably accounting for a large part of the missing factor that places Grade 1 barleys above the position to which their chemical composition would assign to them. A barley grain rich in nitrogen does not normally mature as well, judged by the maltsters' standards, as a grain poor in nitrogen. Usually also an increase in the nitrogen content of the grain is associated with an increased proportion of immature grains. It has been stated that the carbohydrate of a high nitrogen barley is not so completely transformable into extract as that of a low nitrogen barley, and this has been taken as evidence of a connection between maturation and nitrogen content. The statement is true when the grinding is done by the standard method ; as the nitrogen content increases barleys yield progressively less extract than corresponds with replacement of the carbohydrate by the additional

protein. With finer grinding, however, the full amount of extract is obtained. This result suggests some sealing up or rendering inaccessible of carbohydrate in barleys of high nitrogen content.

How nitrogen content is determined.

The effect of various conditions on the nitrogen content of barley can now be set out much more clearly than was possible before. The percentage of nitrogen in the grain is governed by two distinct factors : the amount of nitrate taken up from the soil by the roots, and the amount of carbohydrate synthesised by the leaves. Nitrate assimilation is normally most active in the early part of the plant's life, and carbohydrate synthesis continues much later, but its total amount depends on the quantity of nitrate taken up, so that the two processes, though quite distinct, are nevertheless closely related.

These two factors produce two entirely different effects. Up to a certain quantity, increases in the nitrate supply in the soil correspondingly increase the nitrate uptake by the plant, and this correspondingly increases its carbohydrate assimilation. The yield thus increases but the composition both of plant and of grain hardly changes : the percentage of nitrogen in the grain is unaltered, or slightly rises, or more usually slightly falls. While the yield rises considerably the nitrogen percentage may rise only from about 1.4 to 1.55.

Further increases in soil nitrate supply beyond this stage have a different effect : they raise the nitrogen content of the plant as a whole and of the grain, but do not correspondingly increase the yields. There is no sharp point where increased yield ceases and increased nitrogen content begins ; both effects overlap, but the change is well marked around a certain nitrogen content varying with the environmental conditions. Commonly in the Institute experiments this has been about 1.6 per cent. ; samples containing less than this have been obtained under conditions where the effect of the soil nitrogen has been to increase crop rather than nitrogen content, and samples containing more have been obtained under conditions where the soil nitrogen has been present in larger quantity and has increased the nitrogen content of the grain but not so much the yield.

These results explain much about the effects of soil, season and manuring, and in particular, clear up many of the inconsistencies of the older work which caused so much difficulty in the past. Much of the "nitrogen controversy" summarised by Hulton arose because in some of the experiments the growth effects have dominated, and in others the nitrogen accumulation effects.

Nitrogen content and variety.

All the varieties tested appeared to be equal in their efficiency as absorbers of nitrate from the soil, but some were more efficient than others as producers of carbohydrate. Thus while all would apparently contain the same quantity of nitrogen if grown side by side under the same conditions, some would produce more carbohydrate, and therefore give larger yields of grain of lower nitrogen content than others. The actual quantity of carbohydrate formed depends on the conditions, but the different varieties always come out in the same order of yield and nitrogen content; the general pattern of each, as already stated, remains unaltered. High-yielding varieties contain lower percentages of nitrogen than low-yielding varieties grown under similar conditions; and there is no indication of any possibility of producing high-yielding varieties of high nitrogen content.

For any given variety, however, it is possible within the limits imposed by its pattern to vary the proportions of carbohydrate and nitrogen as well as their absolute amounts, and so to obtain high or low yields above or below the average in nitrogen content. The methods of doing this have been studied in detail.

Factors causing variation in nitrogen content of any given variety.

The chief factors influencing nitrogen content of barley are soil and season; manuring is important chiefly as affecting yield. The variations in nitrogen content of grain due to season are least on heavy soils and on loams and greatest on sands: here they were very marked, indeed sands gave us both our highest and our lowest nitrogen barleys. The variations in nitrogen content due to manurial treatment on the usual scale are unimportant: the increase in yield brought about by nitrogenous manures is however considerable, and its economic effect

is still further enhanced by the increased valuation assigned by the valuers to manured as against the unmanured barleys.

Perhaps the most striking result of this part of the work has been the tracing out of the effect of weather conditions on the nitrogen content of barley. Rainfall is the chief factor, especially that coming in March and April; it so largely dominates the situation that at the end of June one can from the rainfall figures alone predict the nitrogen content within somewhat narrow limits. Later weather conditions, temperature and sunshine have considerably less effect. While weather conditions cannot be controlled, their effect can be to some extent predicted and there are already possibilities in sight for effecting improvements in the prediction.

Soil conditions, on the other hand, do lend themselves to a considerable degree of control. It is easier in practice to increase the soluble nitrogen of the soil than to decrease it, but its effect can be modified in certain ways, by early sowing and especially by previous fallowing. These conditions are easily obtainable under the new systems of mechanised farming; here, therefore, one would expect high yields of low nitrogen barley.

Factors determining 1,000 corn weight.

The thousand corn weight of barley grain, like the nitrogen content, is largely determined by the weather in spring but in a different way. Like the nitrogen content it is lowered by March rainfall, but February rainfall has an even more potent effect.

Unlike the nitrogen it is raised by increasing temperature in March and April. It is hardly affected by the manuring and has no regular connection with nitrogen percentage. In some years there is a tendency for large grains to have high nitrogen content, but in other years the tendency is just the opposite; when, however, grains from the same sample are sorted out the larger grains tend to have the higher nitrogen content.

Factors causing variation in yield.

Soil and season are again the chief factors, but manuring plays a much more important part than in relation to composition.

Soils rich in organic matter, *e.g.*, the fen soils, gave high yields of high nitrogen content; heavy loams gave good yields, and medium loams gave good, sometimes high, yields of

relatively low nitrogen content ; indeed, our highest yields were from the sandy loam of Barneyhill, near Dunbar. Sands on the other hand usually gave low yields, but with much variation due mainly to variations in water supply.

The effect of season on yield is marked : the most potent factor again is rainfall, and March and April again are the critical months. The action is less simple, however, than on nitrogen percentage, for the spring rain has at least two distinct effects, a harmful effect on the soil, presumably a leaching out of nitrates, and a beneficial effect on the crop some five to eight weeks after sowing. Yields have not yet been forecasted from a knowledge of weather conditions, but already the Rothamsted workers are able to account for something like one-third of the annual variance on a light soil, and it is probably only a matter of time before much of the remainder is satisfactorily explained.

The use of fertilisers for securing high yield without detriment to quality has

been dealt with in the agricultural journals and need not be discussed at length here. Nitrogenous manuring is the chief factor, and on the whole, sulphate of ammonia is the best of the nitrogenous manures though the muriate would be somewhat better if it were obtainable. Phosphatic manuring gave good responses on certain soils but not on all, one factor being the residual effect of previous liberal dressings for the root crop. With the reduction in area of roots, however, the question of phosphatic manuring becomes more important, especially where the barley is grown after a fallow. Potassic manuring on the other hand had little beneficial effect except on the light sands, and these present other peculiarities : phosphates have not infrequently harmful effects, and the nitrogen content of their barleys is widely scattered. We found no evidence of any important effect of potash or phosphates in improving the valuation or the nitrogen content of the barley grown on ordinary agricultural soils.

SECTION VII.

Author Index.	Page		Page
Arnold, C. W. B.	294	Lancaster, H. M.	288, 289, 290, 309
Baird, Messrs. Hugh & Sons	290	Ling, A. R.	291
Beaven, E. S. 288, 289, 291, 293, 295, 308, 310, 311, 321, 328, 332, 339		Lisle, E.	308
Bishop, L. R. 289, 291, 293, 294, 296, 317		Luers, H.	294
Brenchley, W. E.	313	Mann, A.	309
Brown, H. T.	288, 294, 297	Mitchell, W. J.	297
Campbell, G. F.	294	Munro, J. M. H.	288, 293, 310, 321
Chapman, A. Chaston	307	Northampton Brewery Co.	290
Cherry-Downes, H. D.	289	Osborne, T. B.	291, 294
Clapham, A. R.	320	Preece, I. A.	291
Crowther, E. M.	294	Reid, R. V.	289, 309
Day, F. E.	288, 289, 290	Schramm, E.	316
Ehrich, E.	293	Stadler, H.	294
Fuller, Smith & Turner, Messrs.	290	O'Sullivan, C.	288
Furst, F.	331	Taylor, H. Stanley	310
Georges & Co., Ltd.	290	Threadgold, H.	294
Gilbert, J. H.	321	Truman, Hanbury & Buxton & Co	290
Gilstrap Earp & Co.	290	Watkin, J. E.	321
Gregory, F. G.	332	Webster, A. M.	320, 321
Gunnness, Messrs. Arthur, Son & Co.	336	Weigert, J.	331
Hall, A. D.	313	Wiesmann, H.	316
Harlan, H. V.	309	Wightman, O.	289
Harrison, T. J.	309	Younger, William & Co.	290
Hawkes, F. C.	330		
Hind, H. Lloyd	288, 289, 290, 294, 305		
Hoffman-Bang, G.	293		
Hooker, R. H.	317		
Hopkins, R. H.	294		
Hulton, H. F. E.	288, 296, 339, 341, 342		
Hunter, H.	310		
Ivanoff, N. N.	293		
Kneip, E.	293		
Knowles, F.	321		
Kraft, W.	294		

Subject Index.

Barley varieties are given in inverted commas “ ”

	Page
Acidity in soil	337
Agdell Field.	310
Amide Nitrogen in wort	297
Amino Nitrogen in wort	297
“ Archer ”	289, 297, 332, 333
“ Archer-Goldthorpe ”	332, 333
“ Atlas ”	297, 307
Autumn Sowing	330, 337

<i>Barley.</i>	Page	<i>Extract.</i>	Page
Carbohydrates	291, 307	Relation to Barley analysis ..	294-297, 308, 339
Composition	290-294, 307	Effect of nitrogen	294-297, 308, 339
Development of	291, 293	Effect of Thousand Corn Weight ..	.. 297
<i>Grade.</i>		Effect of variety	297, 300, 308, 340
Relation to malt grade ..	300-305, 308, 340	Progressive increase in .. .. .	.. 310
Relation to beer quality ..	.. 307, 308	Eye .. .. .	.. 319
<i>High Nitrogen.</i>		Eyton .. .. .	.. 324, 327
Effect on beer flavour ..	307, 308, 340	" F.112 " .. .. .	.. 305, 307
Value of .. .. .	.. 289	Fertilisers, <i>see</i> Manuring.	
Low Nitrogen	307, 308, 340	Field Experiments	289, 310, 311
Maltsters' and Brewers' requirements ..	308, 310	" Garton's 1917 " .. .. .	.. 332
<i>Nitrogen Content</i> .. .. .	.. 307	Glutelin	292, 293, 307, 339
Conditions governing ..	314, 317-324, 341	" Golden Pheasant "	297, 300, 332
During development .. .. .	.. 313	" Golden Archer "	297, 332
Effect of fallow on	327, 328	" Goldthorpe "	310, 332
Effect of fertiliser on	321	Good Easter .. .. .	.. 330
Effect of rainfall on	320	Hemi-cellulose .. .. .	.. 291
Effect of season on	319-321, 342	Hordein	291, 292, 293, 307, 339
Effect of soil conditions on ..	317-319, 341	Hoos Field 310, 311, 314, 321, 322, 323, 328, 332, 333	
Effecture of temperature on ..	.. 321	Indian Barley .. .. .	.. 300, 307
Effect of variety on	332, 333, 342	Insoluble Carbohydrate	297, 307, 308
Early sowing	329, 330, 337	Institute of Brewing 288, 295, 298, 300, 301, 302,	
Factors decreasing .. .. .	.. 335	305, 307, 309, 311, 313, 314, 319, 321, 322, 324,	
Factors increasing .. .. .	.. 333	327, 329, 330, 333, 341	
Forecasting, possibility of ..	335-336	<i>Investigations.</i>	
Late Sowing	329, 330	Methods of	289-290
Relation to beer flavour	307, 308	Programme of	288, 289-290, 339
Relation to malt grade	303, 304, 308	Previous	288-289, 310, 321, 339
Relation to malt nitrogen content ..	.. 297	Ireland. Yields in .. .. .	.. 317
Relation to permanently soluble nitrogen	297, 300, 308	Lincoln Heath .. .. .	.. 320
Relation to Thousand Corn Weight	324, 325	Long Sutton .. .. .	.. 330
<i>Nitrogen compounds</i>	291-293, 307, 339	<i>Malt.</i>	
Changes in malting .. .. .	.. 294	Grade	301, 303
Phosphorus content	294, 307	Grade Relation to Barley Grade	303-304, 308
Proteins, <i>see</i> barley nitrogen compounds.		<i>Malting</i> .. .. .	.. 289
Steely	293, 339	Malting Loss	298, 308
Yield-variety relations	332-334	Effect of changing conditions ..	.. 298
Varieties, <i>see</i> Variety.		Effect on Nitrogen compounds ..	294, 340
Barley Committee. 288, 289, 290, 291, 294, 296, 297,	309, 310, 321, 340	<i>Manuring and Fertilisers.</i>	
Barneyhill	327	Effect on Nitrogen content	321-324, 343
" Beaven's Archer "	332	Effect on Yield	314-317, 322, 337, 343
" Beaven's 25 "	332	Effect on Valuation	326, 343
" Beaven's 1920 "	332	Hoos Field Results	311, 321
Brewers' Exhibition	309	Nitrogenous	314, 322, 337, 343
<i>Brewing.</i> —Large Scale	305-306, 308	Nitrogenous, differences between 322, 324, 337, 343	
Small Scale	306-307, 308	Nitrogenous, effect on barley nitrogen content 313,	
Bulk Malting, <i>see</i> Stocking.		321-324	
Californian Barley	297, 305, 307, 336	Nitrogenous, late application of ..	.. 322
Cawkwell	319	Nitrogenous, sales of .. .. .	.. 311
Cellulose	291	Phosphatic	316, 322, 337, 343
Chevallier	309, 332	Potassic	316, 322, 337, 343
Chisleborough	321, 327	Martlesham	321, 327
Cold Water Extract	298, 308	Maturation .. .. .	.. 341
Colour	298, 308	Missing Factor in extract calculation ..	302, 308
Cork. Barleys from	336	National Institute of Agricultural Botany	289, 330
<i>Crop Rotation.</i>		Nitrogen Content, <i>see</i> Barley.	
Effect on Barley	326-327	Norfolk	316, 337
<i>Cultivation Treatments.</i>		Nynehead .. .. .	.. 327
Effect on Yield	328-329	<i>Permanently Soluble Nitrogen.</i>	
Rotary	329	Relation to Barley nitrogen	297, 308
Diastase	294, 298, 308	Peptide Nitrogen in wort .. .. .	.. 297
<i>Drilling Width.</i>		" Plumage-Archer " 289, 292, 293, 295, 297, 300,	
Effect on Barley	328, 337	307, 310, 311, 322, 329, 330, 331, 332, 333, 334,	
Eastern Counties .. .. .	.. 317	337, 339	
Essex	330, 337	Porlock .. .. .	.. 327
		Proteins, <i>see</i> Barley and Malting.	

	Page		Page
<i>Quality</i>	300, 308, 337	<i>Temperature—continued</i>	
Brewers' requirements for	308-309	Effect on Yield	317, 337
Maltsters' requirements for	308-309	"Tennessee Winter"	297
<i>Rainfall.</i>		<i>Thousand Corn Weight.</i>	
Effect on Nitrogen Content	320, 342	Effect of early Sowing on	329
Effect on Thousand Corn Weight ..	324, 342	Effect on extract	297
Effect on Yield	316, 317, 343	Effect of fertiliser on	324, 325
<i>Ripening.</i>		Effect of season on	324, 342
Effect on Barley nitrogen content ..	313	Effect of soil on	324
Rothamsted Experimental Station 289, 309, 310,		Effect of late sowing on	329
311, 314, 316, 317, 320, 321, 327, 328, 329,		Relation to Nitrogen content ..	324, 325
331, 332, 333, 343		Tuborg Laboratory	293
Salt-soluble nitrogen	292, 293, 307, 339	Two-rowed Barley, <i>see</i> Variety.	
Scotland, yields in	317	<i>Undersowing.</i>	
<i>Season.</i>		Effect on Barley	328
Effect on Barley nitrogen content 313, 319-321,		<i>Valuation</i>	289
335, 337, 342		Effect of autumn sowing on ..	330
Effect on Thousand Corn Weight 324, 335, 342		Effect of fertilisers on	326
Effect on Yield	316-317, 337, 335, 343	Effect of soil conditions on ..	325
<i>Seeding Rate.</i>		Effect of variety on	332
Effect on Barley	328, 337	Valuation Sub-Committee ..	289, 300, 310
Six-rowed barley, <i>see also</i> Variety 293, 297, 305		<i>Variety.</i>	
<i>Soils</i>	289	Tests	289, 330-333, 342
Effect on Nitrogen Content	317-319, 342, 343	Effect of malting conditions on ..	300
Effect on Quality	308, 337	Extract constants	297
Effect on Valuation	304, 325	and improvement of Extracts ..	310
Effect on Yield	314-316, 342-343	History of English varieties ..	310
Effect on Proteins	293	Yield relations	330-332, 342
"Spratt-Archer" 289, 295, 297, 307, 310, 322, 330,		Walcot	319
331, 332, 337		Weather, <i>see</i> Season.	
Sprowston	324, 327, 328, 330, 337	Wellingore	313, 319, 320, 321, 327
Stackyard field	310, 332, 333	Woburn Experimental Station 289, 310, 311, 313, 314,	
Starch	291, 297, 311	315, 316, 317, 320, 321, 322, 324, 327, 328, 329,	
Statistical Methods	289, 339	331, 332, 333, 335	
<i>Stocking Malting</i>	289	<i>Yield.</i>	
Comparison with bulk	290	Effect of early Sowing on ..	329, 330, 337
Sowing Date	329, 330, 337, 342	Effect of Fallow	327, 328
Suffolk	319	Effect of Fertiliser on	314-316, 343
<i>Sunshine.</i>		Effect of Season on	316-317, 343
Effect on Yield	317	Effect of soil conditions on ..	314-316, 342-343
<i>Temperature.</i>		Effect of variety on	331, 332, 342
Effect on nitrogen content	321, 337, 342	Effect of late Sowing on ..	329
Effect on Thousand Corn Weight ..	324	Nitrogen content—variety relations ..	332, 334
		Possibility of Forecasting ..	335-336, 343
		Recent rise in	311

APPENDIX.

PRIMARY DATA FROM TEN YEARS OF BARLEY EXPERIMENTS BY THE INSTITUTE OF BREWING, 1922-31.

Stocking maltings by H. M. Lancaster.

Analyses of barleys and malts

for seasons 1922-26 by H. Lloyd Hind, B.Sc., F.I.C.

for seasons 1927-31 by F. E. Day, B.Sc., F.I.C.

Yields are given as weighed bushels (56 lb.) unless otherwise stated. Where available, yields of dressed grain are given ; in other cases total grain is given.

Total nitrogen percentages, thousand corn weights, malting losses, extracts on malt and barley, and permanently soluble nitrogen percentages are calculated on dry matter. Moistures, diastatic powers, and cold water extracts are calculated as percentages on original samples.

" D " after valuation figure signifies damaged grain.

" Gr " instead of valuation signifies grinding class.

Section. pp.

- I 347 to 357 Large Malting Barleys Plots, 1st Series (5 plots).
 - II 358 to 365 Large Malting Barleys Plots, 2nd Series.
Sulphate and Muriate of Ammonia and No Nitrogen Plots.
 - III 366 to 392 Small, Replicated Plot, Manurial Experiments, 2nd Series.
 - IV 393 to 396 Miscellaneous Experiments, Rothamsted and Outside Centres.
 - V 397 to 402 Permanent Barley Plots, Rothamsted, Great Hoos Field.
 - VI 403 to 418 Variety Trials, National Institute of Agricultural Botany and Associated Centres.
 - VII 419 to 421 Miscellaneous Experiments, Norfolk Agricultural Station.
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SECTION I. (TABLE 2). SEASON 1923.

Five Plot Barleys.

Sample No.	Manurial Treatment.	Barley.						Malt.					Market valuation by sub-committee. Shillings.	
		Yield. Bushels per Acre.	Moisture per cent.	1,000 corn weight dry. Grams.	Nitrogen per cent. on dry.	M/L as % of Dry Matter.	Extract per 448 lb. Raw Barley.	Moisture per cent.	Extract lb. per quarter on dry.	Colour.	Diastatic Power. Lintner°.	Cold water extract per cent.		
													Barley per 448 lb., Jan., 1924.	Malt per 336 lb., Jan., 1924.
SIR HARRY HOPE, BARNEYHILL, E. LOTHIAN, N.B.														
(Soil: Loam over Lower Trias.)														
2	Unmanured ..	63.0	16.2	39.2	1.59	6.6	104.1	1.5	99.6	4.2	29.0	18.5	50	70
3	Complete manure ..	72.0	16.0	37.8	1.68	7.7	101.7	1.7	98.8	4.7	34.0	19.0	49/6	70
4	Without potash ..	68.5	15.9	37.0	1.82	7.5	100.2	1.9	97.3	4.5	34.0	19.0	49/6	65
5	Without phosphate ..	73.0	16.5	38.3	1.74	7.9	100.3	1.8	98.0	5.0	34.0	18.8	49	65
6	Without nitrogen ..	71.0	16.4	36.5	1.73	7.0	101.7	1.6	98.3	4.5	32.5	18.8	49	65
	Average ..	69.5	16.2	37.8	1.71	7.3	101.6	1.7	98.4	4.6	32.7	18.8	49/6	67

A. E. DAVY, CAWKWELL, Lincs.

(Soil: Light Loam over Chalk.)

14	Unmanured ..	40.0	19.1	42.5	1.40	6.2	102.9	1.8	101.4	3.5	35.0	18.3	41/6	70
15	Complete manure ..	43.3	18.5	41.2	1.36	6.5	103.3	1.7	101.8	3.7	35.0	17.8	42	70
16	Without potash ..	44.8	18.7	41.7	1.58	6.5	102.2	1.9	100.8	3.5	40.0	18.1	41/6	70
17	Without phosphate ..	42.8	19.1	42.4	1.57	6.5	101.2	1.8	100.4	3.5	37.5	18.3	41	70
18	Without nitrogen ..	35.0	19.3	42.0	1.53	6.0	101.7	1.6	100.7	3.7	38.0	18.0	41/6	70
	Average ..	41.2	18.9	42.0	1.49	6.3	102.3	1.8	101.0	3.6	37.1	18.1	41/6	70

G. H. NEVILLE, WELLINGORE, Lincs.

(Soil: Loam over Oolite.)

19	Unmanured ..	40.8	15.3	40.4	1.49	6.8	107.0	1.6	101.7	4.7	33.5	20.9	52	75
20	Complete manure ..	45.8	15.3	39.3	1.46	7.7	105.9	1.7	101.8	5.7	32.0	21.1	52	75
21	Without potash ..	43.8	15.3	39.2	1.44	8.3	104.1	1.8	101.1	5.7	29.5	22.1	53	75
22	Without phosphate ..	46.4	15.1	39.4	1.44	8.1	105.6	1.7	101.4	5.0	33.5	21.4	52	75
23	Without nitrogen ..	39.2	14.9	38.9	1.38	8.1	105.8	1.8	101.6	5.2	32.0	22.2	53	75
	Average ..	43.2	15.2	39.4	1.44	7.8	105.7	1.7	101.5	5.3	32.1	21.5	52/6	75

E. CRAIG TANNER, EYTON-ON-SEVERN, SALOP.

(Soil: Loam.)

24	Unmanured ..	33.1	16.6	36.6	1.82	8.8	99.5	1.8	98.1	5.0	39.0	19.6	48	65
25	Complete manure ..	47.3	16.5	39.3	1.63	7.5	103.6	1.8	100.7	5.2	34.5	19.4	49	75
26	Without potash ..	47.6	16.8	36.4	1.64	7.1	103.1	1.7	100.0	4.7	34.0	17.3	49	75
27	Without phosphate ..	44.4	16.3	41.0	1.79	8.8	101.9	2.0	100.1	4.7	38.5	18.2	49	75
28	Without nitrogen ..	40.0	16.5	39.8	1.59	7.5	104.9	1.7	101.8	4.3	33.5	17.4	50	77
	Average ..	42.5	16.5	38.6	1.70	7.9	102.6	1.8	100.1	4.8	35.9	18.4	49	73

R. A. CLARKE AND SONS, CHISELBOROUGH, SOMERSET.

(Soil: Loam over Inferior Oolite.)

29	Unmanured ..	27.0	17.8	40.3	1.49	6.9	102.9	1.6	100.9	3.7	33.5	19.0	47	80
30	Complete manure ..	29.0	17.4	41.0	1.40	7.2	103.0	1.7	101.2	4.0	33.0	19.7	47	80
31	Without potash ..	26.2	17.8	40.4	1.54	6.8	103.1	1.6	100.8	3.7	33.0	19.3	47	80
31A	Without phosphate ..	27.0	17.5	42.5	1.55	7.0	101.9	1.5	99.8	4.0	33.0	19.7	47	80
31B	Without nitrogen ..	19.5	17.5	43.3	1.52	7.5	101.6	1.6	100.0	4.5	—	—	46	80
	Average ..	25.7	17.6	41.5	1.50	7.1	102.5	1.6	100.5	4.0	33.1	19.4	47	80

SECTION I. (TABLE 2). SEASON 1923.

Five Plot Barleys.

Sample No.	Manurial Treatment.	Barley.						Malt.					Market valuation by sub-committee. Shillings.	
		Yield. Bushels per Acre.	Moisture per cent.	1,000 corn weight dry. Grams.	Nitrogen per cent. on dry.	M/L as % of Dry Matter.	Extract per 448 Raw Barley.	Moisture per cent.	Extract lb. per quarter on dry.	Colour.	Diastatic Power. Lintner°.	Cold water extract per cent.		
													Barley per 448 lb., Jan., 1924.	Malt per 336 lb., Jan., 1924.

RT. HON. E. G. PRETYMAN, ORWELL PARK, SUFFOLK.

(Soil : Sand.)

32	Unmanured ..	7.8	16.9	31.5	1.98	10.2	93.8	1.8	94.1	5.7	39.0	22.3	40	55
33	Complete manure ..	10.8	15.9	32.6	1.93	10.2	96.1	1.6	96.0	5.7	40.0	22.7	40	55
34	Without potash ..	5.5	16.0	34.4	1.89	9.8	96.2	1.6	95.3	6.5	38.0	23.0	40	55
35	Without phosphate ..	11.2	16.2	29.8	1.99	10.3	93.0	1.6	93.5	6.5	40.0	22.4	40	55
36	Without nitrogen ..	8.1	16.4	34.2	1.86	10.2	92.9	1.3	93.5	7.0	41.5	22.8	40	55
	Average ..	8.7	16.3	32.5	1.93	10.1	94.4	1.6	94.5	6.3	39.7	22.6	40	55

C. BEMBRIDGE, WALCOTT, LINCS.

(Soil : Fen.)

38	Unmanured ..	50.3	17.0	41.9	1.87	8.4	98.2	1.8	96.2	6.2	40.0	21.6	41	60
39	Complete manure ..	48.8	16.6	43.6	1.82	9.2	99.5	1.9	97.5	6.2	39.5	20.7	41	60
40	Without potash ..	50.0	17.0	43.3	1.81	8.6	96.6	1.8	95.5	6.5	34.0	22.6	41	60
41	Without phosphate ..	47.5	17.6	43.5	1.79	8.0	98.4	1.9	97.3	6.2	36.0	20.3	42	60
42	Without nitrogen ..	44.1	18.1	44.0	1.73	8.5	97.2	1.9	97.3	6.2	34.0	20.7	41	60
	Average ..	48.1	17.3	43.3	1.80	8.5	98.0	1.9	96.8	6.3	36.7	21.2	41/6	60

B. HILL, EAST DEREHAM, NORFOLK.

(Soil : Sand over Chalk.)

43	Unmanured ..	21.5	18.1	34.2	1.94	9.4	94.7	1.9	95.7	6.2	43.0	21.9	39	55
44	Complete manure ..	26.5	18.5	34.7	1.99	9.2	93.9	1.7	94.9	6.2	40.5	22.7	40	55
45	Without potash ..	20.8	18.5	35.9	2.06	9.1	93.9	1.9	94.9	7.0	46.0	22.4	40	55
46	Without phosphate ..	22.0	18.7	35.8	2.01	10.2	92.5	1.8	95.4	6.5	46.0	22.6	40	55
47	Without nitrogen ..	20.4	18.2	34.5	2.02	9.9	95.1	1.6	96.5	6.2	44.5	22.1	40	55
	Average ..	22.2	18.4	35.0	2.00	9.6	94.0	1.8	95.5	6.4	44.0	22.3	40	55

J. H. SPILMAN, BEVERLEY, YORKS.

(Soil : Loam over Chalk.)

48	Unmanured ..	36.8	19.0	38.5	1.29	6.9	100.1	1.8	99.9	4.2	24.0	19.7	43	65
49	Complete manure ..	50.3	19.4	41.6	1.34	8.0	98.3	1.9	99.3	4.0	27.2	19.4	41	65
50	Without potash ..	54.8	18.9	40.4	1.38	7.0	99.2	1.8	98.8	4.0	28.0	19.5	43	65
51	Without phosphate ..	46.6	18.8	40.4	1.38	6.7	99.6	2.1	98.4	4.0	29.5	19.3	43	65
52	Without nitrogen ..	38.6	19.7	38.6	1.30	6.4	99.4	1.9	99.0	3.8	27.2	18.9	43	65
	Average ..	45.4	19.2	39.9	1.34	7.0	99.3	1.9	99.1	4.0	27.2	19.4	42/6	65

SECTION I. (TABLE 2). SEASON 1923.

Five Plot Barleys.

Sample No.	Manurial Treatment.	Barley.						Malt.					Market valuation by sub-committee. Shillings.	
		Yield. Bushels per Acre.	Moisture per cent.	1,000 corn weight dry. Grams.	Nitrogen per cent. on dry.	M/L as % of Dry Matter.	per 448 Raw Barley.	Moisture per cent.	Extract per 336 Dry Malt.	Colour.	Diastatic Power. Lintner.	Cold water extract per cent.	Barley per 448 lb., Jan., 1924.	Malt per 336 lb., Jan., 1924.

HARPER ADAMS AGRICULTURAL COLLEGE, NEWPORT, SALOP.

(Soil: Loam over Lower Trias.)

43	Unmanured ..	22.0	18.5	44.3	1.62	7.2	98.9	1.6	98.2	4.2	39.0	19.2	42	60
54	Complete manure ..	30.6	19.0	43.1	1.79	6.5	98.4	1.5	97.4	4.5	39.0	18.9	42	60
55	Without potash ..	33.7	18.7	43.0	1.77	8.0	96.7	1.5	96.9	4.5	40.5	18.8	42	60
56	Without phosphate ..	30.2	18.2	42.8	1.74	7.2	98.7	1.5	97.7	4.0	38.0	19.4	42	60
57	Without nitrogen ..	33.8	17.6	43.7	1.80	8.1	98.4	1.5	97.4	4.5	42.0	19.7	42	60
	Average ..	30.1	18.4	43.4	1.74	7.4	98.2	1.5	97.5	4.3	39.7	19.2	42	60

WOBURN EXPERIMENTAL STATION, APSLEY GUISE, BEDS.

(Soil: Sand, Lower Greensand.)

68	Unmanured ..	33.6	19.1	41.7	1.92	7.7	94.9	1.9	95.0	10.5	34.0	21.5	43	55
69	Complete manure ..	43.1	17.9	41.0	1.77	6.5	97.1	1.6	94.7	6.5	30.0	19.4	56	55
70	Without potash ..	40.6	17.7	40.2	1.69	5.8	94.6	1.5	91.2	6.2	28.0	17.9	56	55
71	Without phosphate ..	38.1	17.7	39.3	1.61	7.5	98.5	1.5	96.4	5.0	27.0	19.1	57	55
72	Without nitrogen ..	30.5	18.7	38.9	1.54	5.6	97.3	1.5	95.2	4.2	25.0	18.7	58	55
	Average ..	37.2	18.2	40.2	1.71	6.6	96.5	1.6	94.5	6.5	28.8	19.3	54	55

DR. E. S. BEAVEN, WARMINSTER, WILTS.

(Soil: Loam over Lower Greensand.)

75	Unmanured ..	36.7	13.6	43.6	1.53	7.7	103.0	1.3	101.5	5.2	38.0	21.9	52	73
76	Complete manure ..	43.1	13.6	41.5	1.46	7.2	103.7	1.4	102.4	5.0	38.0	22.6	52	75
77	Without nitrogen ..	35.4	13.1	44.0	1.39	8.1	103.7	1.5	102.6	5.0	35.5	22.8	52	75
78	Without potash ..	42.3	13.3	42.5	1.46	8.3	102.7	1.5	101.8	5.2	38.0	22.4	52	75
79	Nitrogen only ..	—	13.7	44.0	1.51	7.9	102.4	1.6	101.7	5.0	38.0	21.6	52	75
80	Unmanured ..	32.0	13.4	45.1	1.56	8.4	101.7	1.6	100.9	5.5	40.0	22.5	51	75
	Average ..	37.9	13.4	43.4	1.48	7.9	102.9	1.5	101.8	5.2	37.9	22.3	52	75

ROTHAMSTED EXPERIMENTAL STATION, HARPENDEN, HERTS.

Malting Barley Set, Long Hoos Field.

(Soil: Clay over Chalk.)

81	Unmanured ..	21.4	16.4	—	1.71	8.7	100.9	2.2	99.3	6.5	37.0	22.7	56	75
82	Complete manure ..	32.8	17.0	43.2	1.54	8.5	102.3	2.0	101.0	6.3	32.5	22.7	57	75
83	Without potash ..	33.9	17.8	41.7	1.55	6.8	103.4	1.8	101.2	6.5	31.7	21.9	57	77
84	Without phosphate ..	33.8	18.0	42.4	1.58	6.4	103.4	2.0	101.0	5.2	33.3	20.8	57	77
85	Without nitrogen ..	19.5	17.0	41.3	1.65	7.7	100.5	2.1	98.4	7.0	34.2	22.9	56	75
86	as 83 + M/Potash ..	37.3	16.3	41.0	1.63	8.0	104.6	2.1	101.9	5.0	30.7	21.2	58	77
87	as 85 + M/Ammonia ..	35.7	16.7	41.8	1.48	7.9	103.8	2.2	101.2	4.7	31.7	22.0	58	77
	Average (81-85)	28.3	17.2	42.2	1.61	7.6	102.1	2.0	100.2	6.3	33.0	22.0	57	76

SECTION I. (TABLE 3). SEASON 1924. Five Plot Barleys.

For Manurial Treatments see heading of Table 1.

Sample No.	Plot.	Barley.						Malt.					Market valuation by sub-committee. Shillings.	
		Yield dressed grain Bushels per acre.	Moisture per cent.	1,000 corn weight (grms.) dry.	Nitrogen per cent. on dry.	Making loss per cent. on dry.	Extract calculated to 448 lb. raw.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic Power. Lintner°.	Cold water Extract per cent.	Barley, 448 lb., Nov., 1924.	Malt, 336 lb., Dec., 1924.
9	1	27.9	19.44	39.1	1.564	9.6	95.0	2.18	97.9	6.7	26.0	18.9	67	80
10	2	38.3	17.28	40.0	1.447	9.5	98.9	1.94	98.9	6.7	26.0	19.0	68	80
11	3	45.2	18.24	39.2	1.438	9.6	97.4	2.34	99.8	5.5	24.5	19.9	70	85
12	4	40.4	18.12	40.4	1.425	9.1	98.3	1.92	99.0	5.2	25.0	19.7	70	85
13	5	33.7	16.94	41.3	1.460	9.1	99.6	2.18	98.9	4.5	24.5	19.4	70	85
Average		37.1	18.00	40.0	1.463	9.4	97.8	2.11	98.9	5.7	25.2	19.4	69	83

W. HASLER, DUNMOW, ESSEX.

(Medium to heavy clay loam.)

9	1	27.9	19.44	39.1	1.564	9.6	95.0	2.18	97.9	6.7	26.0	18.9	67	80
10	2	38.3	17.28	40.0	1.447	9.5	98.9	1.94	98.9	6.7	26.0	19.0	68	80
11	3	45.2	18.24	39.2	1.438	9.6	97.4	2.34	99.8	5.5	24.5	19.9	70	85
12	4	40.4	18.12	40.4	1.425	9.1	98.3	1.92	99.0	5.2	25.0	19.7	70	85
13	5	33.7	16.94	41.3	1.460	9.1	99.6	2.18	98.9	4.5	24.5	19.4	70	85
Average		37.1	18.00	40.0	1.463	9.4	97.8	2.11	98.9	5.7	25.2	19.4	69	83

A. E. DAVY, CAWKWELL, SCAMBLESBY, LOUTH, Lincs.

(Chalk wolds.)

14	1	40.2	20.32	36.9	1.266	8.6	97.2	1.76	100.2	4.0	25.0	17.5	65	95
15	2	42.2	20.54	37.2	1.199	8.1	97.9	1.62	100.3	4.0	23.0	18.1	65	95
16	3	38.1	19.94	38.0	1.253	8.2	98.8	1.80	100.7	4.2	23.5	17.5	65	95
17	4	40.2	20.49	37.1	1.204	8.0	98.0	1.98	100.4	4.5	24.0	18.1	63	95
18	5	33.6	20.85	37.7	1.194	7.9	97.5	2.00	100.4	4.0	23.0	17.9	63	95
Average		38.9	20.43	37.4	1.223	8.2	97.9	1.83	100.4	4.1	23.7	17.8	64	95

G. H. NEVILE, WELLINGORE, Lincs.

(Lincoln Heath, Light Loam.)

19	1	43.3	17.88	39.2	1.424	8.8	97.5	1.94	97.7	9.5	24.5	20.5	72	80
20	2	50.8	17.82	39.3	1.404	9.6	97.7	1.92	98.7	9.5	19.0	22.4	71	80
21	3	58.2	18.00	40.9	1.403	8.7	99.3	1.90	99.5	8.5	23.0	21.6	70	80
22	4	49.9	18.21	38.8	1.449	8.6	99.2	1.66	99.4	7.2	23.0	21.7	70	80
23	5	45.2	18.25	40.3	1.400	8.6	98.8	1.74	99.0	9.5	22.0	21.4	72	80
23A	*		16.76	38.9	1.424	10.6	97.9	1.68	98.8	9.0	26.0	21.8	72	80
Average	19-23	49.5	18.03	39.5	1.421	9.1	98.4	1.83	98.9	8.8	23.5	21.9	71	80

E. CRAIG TANNER, EYTON-ON-SEVERN, SHROPSHIRE.

(Trias red medium loam, gravelly.)

24	1	29.3	17.75	39.2	1.388	8.6	98.8	2.10	98.8	5.2	25.5	19.0	66	103
25	2	49.1	17.46	39.6	1.374	8.3	99.5	1.78	99.1	5.2	25.0	19.3	66	103
26	3	52.6	17.54	40.0	1.361	8.0	100.8	1.63	99.6	5.0	24.5	19.1	66	100
27	4	49.3	17.39	40.0	1.328	7.6	101.7	1.60	100.0	5.2	22.0	18.7	66	82
28	5	45.1	17.76	39.2	1.356	8.4	100.3	1.78	99.8	5.2	24.5	18.9	70	82
Average		45.1	17.58	39.6	1.361	8.2	100.2	1.80	99.5	5.2	24.3	19.0	66	82

* Surface sown after Beet residues

SECTION I. (TABLE 3). SEASON 1924.

Five Plot Barleys.

Sample No.	Plot.	Barley.						Malt.						Market valuation by sub-committee. Shillings.	
		Yield dressed grain Bushels per acre.	Moisture per cent.	1,000 corn weight (grms.) dry.	Nitrogen per cent. on dry.	Making loss per cent. on dry.	Extract calculated to 448 lb. raw.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic Power.	Lintner.	Cold water Extract per cent.	Barley, 448 lb., Nov., 1924.	Malt, 336 lb., Dec., 1924.
R. A. CLARKE & SONS, CHISELBOROUGH, STOKE-UNDER-HAM, SOMERSET.															
(Light sandy soil. Loam.)															
29	1	27 0	20.22	36 4	1 461	8 5	97.0	2.18	99.4	4 7	25 5	18.2	74	100	
30	2	33 0	19.87	37 4	1 403	8 5	96.3	2.10	98.7	5.5	26 0	19.0	74	103	
31	3	27 0	19.94	38 0	1 510	8 8	95.3	1.86	98.1	5 5	25 0	19.1	74	95	
31A	4	27 0	20.03	38 1	1 495	9 0	95.1	1.86	98.1	5 0	23 0	18.9	74	100	
31B	5	27 0	20.06	37 0	1 451	8 5	95.8	1.86	98.3	4 8	24 0	18.7	68	100	
Average		28.2	20.02	37.4	1.464	8.7	96.7	1.97	98.5	5.1	24.7	18.8	73	100	

RT. HON. E. G. PRETYMAN, ORWELL PARK, MARTLESHAM, SUFFOLK.

<i>(Light sand.)</i>															
32	1	12 0	19.32	42 7	1 591	9 6	94.6	2.24	97.5	7 5	29 0	22.4		67	93
33	2	25 0	18.44	39 0	1 407	10 4	97.1	2.20	99.9	7 2	31 0	22.7		70	93
34	3	26 0	19.26	41 2	1 631	9 0	96.0	2.22	97.9	7 0	32 0	21.3		64	80
35	4	27 0	18.44	38 2	1 433	9 0	97.6	2.10	98.8	6.5	25.5	22.6		70	93
36	5	28 0	19.10	42 1	1 521	9 4	96.7	2.30	98.9	6.5	29 0	22.7		67	93
Average		23.6	18.91	40.6	1.517	9.5	96.4	2.27	98.6	6.9	29.3	22.3		68	90

C. BEMBRIDGE, WALCOTT, Lincs.

<i>(Black Fen.)</i>															
38	1	46 0	18.50	42 8	1 581	9 9	96.4	2.22	98.6	6.5	31.0	21.2		63	90
39	2	52 6	18.13	44 4	1 586	10 6	95.4	2.42	97.7	6.5	33.5	20.4		63	90
40	3	51 1	18.30	43 1	1 613	11 2	94.6	1.94	98.0	6.5	26.5	21.3		63	90
41	4	49 6	18.36	42 4	1 560	10 4	94.4	1.84	96.8	7 0	30 0	20.8		63	90
42	5	48 9	18.44	43 3	1 575	11 3	93.1	2.00	96.8	7.5	28.5	21.5		63	85
Average		49.6	18.35	43.2	1.583	10.7	94.8	2.08	97.6	6.8	29.9	21.0		63	89

NORFOLK AGRICULTURAL STATION, NEWTON ST. FAITH'S, NORWICH.

<i>(Light loam, overlying gravel.)</i>															
43	1	32.7	18.16	33 0	1 334	10 1	96.0	2.33	97.8	5.5	25.0	19.0		68	93
44	2	47.5	18.42	34.2	1 286	9.6	98.3	2.30	99.4	5.0	21.5	19.7		72	100
45	3	42.2	18.70	32.8	1 363	9.7	95.4	1.90	97.5	6.0	26.0	19.2		72	90
46	4	38.6	17.28	33.7	1 324	10.0	97.9	2.24	98.6	5.5	24.5	19.2		72	97
47	5	41.8	18.18	34.5	1 289	10.5	95.2	1.84	97.6	5.3	24.0	19.0		68	97
Average		40.6	18.15	33.6	1.319	10.0	96.6	2.12	98.2	5.5	24.2	19.2		70	95

HARPER ADAMS AGRICULTURAL COLLEGE, NEWPORT, SALOP.

<i>(Sandy loam.)</i>															
53	1	36.4	17.12	39.2	1 508	9.3	99.5	2.10	99.3	7.0	31.5	21.5		50	80
54	2	34.4	17.86	39.1	1 624	10.4	96.5	2.00	98.5	7.0	32.5	22.1		50	80
55	3	32.5	16.82	40.6	1 631	9.7	98.1	1.96	98.5	8.0	33.5	22.3		50	80
31h	4	33.8	16.30	39.8	1 506	9.8	99.9	1.98	99.1	8.0	32.0	22.0		50	80
31N	5	34.6	16.84	38.6	1 514	9.5	99.3	1.90	99.1	8.0	30.0	22.4		50	80
Average		34.3	16.99	39.5	1.557	9.7	98.6	1.99	98.9	7.6	31.9	22.1		50	80

SECTION I. (TABLE 3). SEASON 1924.

Five Plot Barleys.

Sample No.	Plot.	Barley.						Malt.					Market valuation by sub-committee. Shillings.	
		Yield dressed grain Bushels per acre.	Moisture per cent.	1,000 corn weight (grms.) dry.	Nitrogen per cent. on dry.	Making loss per cent. on dry.	Extract calculated to 448 lb. raw.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic Power. Lintner ² .	Cold water Extract per cent.	Barley, 448 lb., Nov., 1924.	Malt, 336 lb., Dec. 1924.

SOUTH EASTERN AGRICULTURAL COLLEGE, WYE, KENT.

(Loam over chalk.)

58	1	51.8	19.50	40.5	1.741	10.5	93.6	2.18	97.6	6.2	32.0	19.5	74	85
59	2	53.3	20.12	39.2	1.708	9.6	93.9	1.84	97.6	5.5	33.0	20.2	74	82
60	3	57.0	20.72	38.8	1.748	10.9	91.3	2.14	97.2	7.5	30.5	19.9	74	82
61	4	55.1	21.04	39.1	1.750	9.7	93.1	2.08	98.1	7.5	28.0	21.0	74	82
62	5	52.9	21.58	39.4	1.592	9.6	93.0	1.84	98.2	6.5	30.5	20.6	74	85
Average		54.0	20.59	39.4	1.708	10.1	93.0	2.02	97.7	6.6	30.8	20.2	74	83

T. H. RAWLE, PORLOCK, SOMERSET.

(Loam over stone brash.)

63	1	21.8	17.85	38.6	1.295	8.5	100.0	2.34	99.4	5.5	23.0	19.7	87	108
64	2	31.8	16.64	39.4	1.266	8.2	101.8	1.76	99.8	5.5	22.0	19.9	90	110
65	3	34.6	17.60	38.9	1.326	8.5	99.4	1.74	98.8	5.5	20.0	20.3	90	110
66	4	33.7	17.28	37.2	1.268	8.4	101.3	2.06	100.2	5.0	22.0	20.0	90	112
67	5	28.0	16.81	39.8	1.359	9.1	100.2	1.84	99.5	6.0	21.0	20.6	87	108
Average		30.0	17.24	38.8	1.303	8.5	100.6	1.95	99.5	5.5	21.5	20.1	89	110

WOBBURN EXPERIMENTAL FARM, BEDS.

(Sandy loam.)

68	1	21.3	19.28	37.6	1.230	10.2	98.0	1.94	101.4	5.0	21.0	19.4	80	103
69	2	27.9	18.75	37.3	1.161	10.4	96.8	1.82	99.9	5.2	19.0	20.0	90	104
70	3	30.9	18.56	35.8	1.173	9.7	97.8	1.76	99.8	5.5	18.0	20.8	90	106
71	4	37.1	18.57	39.6	1.259	10.3	97.0	1.86	99.6	5.5	22.0	19.2	80	105
72	5	26.2	18.76	38.6	1.310	10.5	95.8	1.86	99.0	5.5	22.0	19.8	72	103
Average		28.7	18.78	37.8	1.227	10.2	97.1	1.85	99.9	5.3	20.5	19.8	82	104

ROTHAMSTED EXPERIMENTAL STATION, HARPENDEN, HERTS.

Malting Barley set, Great Harpenden Field.

(Heavy strong soil, clay with flints.)

81	1	24.6	16.10	40.6	1.620	9.8	97.6	1.84	96.7	7.0	27.0	22.8	60	80
82	2	27.7	17.00	42.4	1.517	10.2	98.0	2.00	98.0	7.0	25.5	21.8	64	80
83	3	32.3	17.28	42.2	1.540	9.2	98.2	2.15	98.0	7.2	28.0	21.2	64	80
84	4	28.9	17.32	41.5	1.525	9.7	97.4	1.56	97.8	6.8	24.5	21.7	64	80
85	5	20.4	17.06	42.2	1.611	10.2	95.9	1.74	96.5	7.5	25.5	23.1	64	80
86	(KCl)	26.8	17.18	41.2	1.479	8.8	98.6	1.66	97.9	6.8	24.5	22.1	64	
87	(AmCl)	28.0	16.83	42.4	1.495	9.7	98.5	2.13	98.3	7.0	26.5	21.7	64	
Average		27.0	16.95	41.8	1.563	9.7	97.9	1.86	97.4	7.1	26.1	22.1		80

SECTION 1. (TABLE 4). SEASON 1925.

Five Plot Barleys.

Sample No.	Plot.	Barley.						Malt.						Market valuation by sub-committee. Shillings.	
		Yield dressed grain. Bushels per acre.	Moisture per cent.	1,000 corn weight (grams.) dry.	Nitrogen per cent. on dry.	Malting loss per cent. on dry.	Extract calculated to 448 lb. raw.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic Power Lintner.	Cold water extract per cent.			
9	1	32.4	19.02	41.2	1.634	11.8	93.1	2.50	97.8	10.5	30.5	22.8	43	69	
10	2	31.0	18.84	41.5	1.708	11.6	93.5	2.12	97.9	9.0	28.0	23.3	43	69	
11	3	44.9	19.16	40.2	1.705	11.5	93.5	2.20	98.0	11.0	38.0	23.8	43	69	
12	4	37.2	18.16	41.1	1.751	13.1	93.5	3.08	98.8	7.5	32.0	23.8	43	68	
13	5	34.2	18.46	40.5	1.691	11.1	94.0	2.42	97.4	8.5	38.0	22.7	43	68	
13N	N	39.5	19.36	41.2	1.831	11.8	91.8	2.12	97.1	10.5	41.5	21.4	41	68	
Average 9-13		36.6	18.73	40.9	1.698	11.8	93.5	2.46	98.0	9.3	33.3	23.3	43	69	

W. HASLER, DUNMOW, ESSEX.

(Medium to heavy clay loam.)

9	1	32.4	19.02	41.2	1.634	11.8	93.1	2.50	97.8	10.5	30.5	22.8	43	69
10	2	31.0	18.84	41.5	1.708	11.6	93.5	2.12	97.9	9.0	28.0	23.3	43	69
11	3	44.9	19.16	40.2	1.705	11.5	93.5	2.20	98.0	11.0	38.0	23.8	43	69
12	4	37.2	18.16	41.1	1.751	13.1	93.5	3.08	98.8	7.5	32.0	23.8	43	68
13	5	34.2	18.46	40.5	1.691	11.1	94.0	2.42	97.4	8.5	38.0	22.7	43	68
13N	N	39.5	19.36	41.2	1.831	11.8	91.8	2.12	97.1	10.5	41.5	21.4	41	68
Average 9-13		36.6	18.73	40.9	1.698	11.8	93.5	2.46	98.0	9.3	33.3	23.3	43	69

G. H. NEVILLE, WELLINGORE, LINCS.

(Lincoln Heath, light loam.)

19	1	36.9	16.52	37.5	1.466	12.1	96.6	2.46	98.9	8.5	31.0	24.2	67	88
20	2	46.2	16.28	36.7	1.528	11.3	98.3	2.16	99.0	9.0	31.0	23.8	70	88
21	3	46.9	16.94	37.0	1.608	12.4	94.8	2.46	98.0	7.5	32.0	24.7	67	75
22	4	43.0	16.97	37.7	1.516	11.3	96.2	2.36	98.2	7.5	34.0	23.3	67	75
23	5	36.5	16.27	37.5	1.449	11.7	96.7	2.18	98.7	8.0	31.0	23.2	70	88
23N	N	41.0	19.10	37.8	1.580	10.5	93.6	2.28	96.9	14.0	33.0	23.4	50	75
23S	*	—	17.33	33.9	1.466	10.7	98.5	2.20	100.0	4.7	24.0	19.4	80	90
Average	19-23	41.7	16.60	37.3	1.513	11.4	96.3	2.36	98.6	8.1	31.8	23.8	68	83

Spratt-Archer barley.

E. CRAIG TANNER, EYTON-ON-SEVERN, SHROPSHIRE.

(Trias red medium loam, gravelly.)

24	1	30.0	16.34	42.3	1.493	12.8	97.9	2.24	100.7	6.0	28.5	21.0	72	90
25	2	54.2	16.02	42.9	1.479	14.1	96.9	2.22	101.0	5.5	28.5	20.8	70	90
26	3	54.0	16.41	43.2	1.648	12.2	96.3	2.44	99.1	4.5	35.0	20.2	68	90
27	4	46.5	16.38	43.4	1.534	11.5	99.0	2.42	100.4	5.5	31.0	21.3	71	90
28	5	43.0	16.20	42.4	1.394	11.8	99.7	2.20	101.3	6.5	25.5	21.5	73	90
28N	N	48.8	16.24	43.7	1.408	12.7	97.5	2.44	100.2	6.0	29.5	20.1	73	90
Average	24-28	46.1	16.27	42.8	1.490	12.5	97.9	2.30	100.5	5.6	29.7	21.0	71	90

R. A. CLARKE & SONS, CHISELBOROUGH, STOKE-UNDER-HAM, SOMERSET.

(Light sandy soil. Loam.)

29	1	23.0	19.68	41.5	1.593	9.0	97.0	2.20	99.7	6.5	29.0	20.9	65	89
30	2	27.0	19.22	42.6	1.674	9.5	96.9	2.44	99.4	8.0	28.5	21.3	70	89
31	3	24.0	19.50	41.3	1.555	9.7	96.7	2.14	99.8	8.5	28.5	20.4	70	89
31A	4	35.0	18.36	41.5	1.471	10.4	98.2	2.12	100.7	7.0	27.0	21.8	70	89
31B	5	33.0	18.56	42.2	1.474	10.5	97.6	2.30	100.5	6.0	28.5	21.2	70	89
31N	N	35.0	19.42	42.9	1.637	10.7	95.7	2.38	99.8	7.0	30.0	20.7	67	89
Average	29-31B	29.5	19.06	41.8	1.553	10.0	97.3	2.24	100.0	7.2	28.3	21.1	69	89

SECTION 1. (TABLE 4). SEASON 1925.

Five Plot Barleys.

Sample No.	Plot.	Barley.							Malt.					Market valuation by sub-committee. Shillings.	
		Yield dressed grain. Bushels per acre.	Moisture per cent.	1,000 corn weight (grams.) dry.	Nitrogen per cent. on dry.	Malting loss per cent. on dry.	Extract calculated to 448 lb. raw.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic Power. Lintner°.	Cold water extract per cent.	Barley, 448 lb., Nov., 1925.	Malt, 336 lb., Dec., 1925.	Not Maltng Quality.
32	1	—	18.20	37.8	2.255	12.7	83.3	2.46	87.7	9.0	38.0	20.5	37	37	Not Maltng Quality.
33	2	—	18.01	36.8	2.228	13.0	83.9	2.36	88.3	12.0	39.0	22.4	37	37	
34	3	—	17.66	38.6	2.435	13.3	83.5	2.30	88.0	17.0	38.0	21.4	37	37	
35	4	—	17.44	37.1	2.247	14.1	85.6	2.18	90.8	12.0	36.0	22.1	37	37	
36	5	—	17.92	37.8	2.226	11.3	88.2	2.10	90.9	12.0	38.5	22.4	37	37	
36N	N	—	18.16	38.7	2.303	13.2	83.7	2.48	88.8	10.5	38.0	21.7	37	37	
Average	32-36	—	17.85	37.6	2.278	12.9	84.9	2.28	89.1	12.4	37.9	21.8	37		

RT. HON. E. G. PRETYMAN, ORWELL PARK, MARTLESHAM, SUFFOLK.

(Light sand.)

32	1	—	18.20	37.8	2.255	12.7	83.3	2.46	87.7	9.0	38.0	20.5	37	37	Not Maltng Quality.
33	2	—	18.01	36.8	2.228	13.0	83.9	2.36	88.3	12.0	39.0	22.4	37	37	
34	3	—	17.66	38.6	2.435	13.3	83.5	2.30	88.0	17.0	38.0	21.4	37	37	
35	4	—	17.44	37.1	2.247	14.1	85.6	2.18	90.8	12.0	36.0	22.1	37	37	
36	5	—	17.92	37.8	2.226	11.3	88.2	2.10	90.9	12.0	38.5	22.4	37	37	
36N	N	—	18.16	38.7	2.303	13.2	83.7	2.48	88.8	10.5	38.0	21.7	37	37	
Average	32-36	—	17.85	37.6	2.278	12.9	84.9	2.28	89.1	12.4	37.9	21.8	37		

NORFOLK EXPERIMENTAL STATION, NEWTON ST. FAITH'S, NORWICH.

(Light loam, overlying gravel.)

43	1	(37.6)*	16.20	33.1	1.546	11.7	95.0	2.20	96.4	8.5	33.5	24.2	45	65	
44	2	(46.8)	16.08	31.9	1.702	12.0	92.2	2.14	93.5	12.0	34.0	25.1	45	63	
45	3	(47.0)	16.88	30.6	1.849	13.6	88.4	1.96	92.6	12.0	35.0	23.5	45	60	
46	4	(43.6)	17.56	32.3	1.708	13.5	89.8	2.10	94.7	9.0	34.0	22.9	45	65	
47	5	(42.2)	16.54	33.5	1.460	11.0	95.7	1.82	96.6	9.5	32.0	24.4	45	65	
47N	N	(42.9)	15.98	33.2	1.779	12.3	92.6	1.92	94.5	10.0	36.0	22.0	45	65	
Average			43.3	16.65	32.3	1.653	12.3	2.04	94.7	10.2	33.7	24.0	45	64	

*Total grain.

J. H. SPILMAN, BEVERLEY, YORKS.

(Chalky loam.)

48	1	—	18.66	37.9	1.536	9.6	94.6	2.34	96.5	5.0	26.0	17.9	40	68	
49	2	—	18.54	38.0	1.591	9.0	96.4	2.01	97.4	5.3	24.0	20.6	40	68	
50	3	—	18.24	37.9	1.544	9.5	96.4	2.28	97.7	6.5	22.5	20.4	40	68	
51	4	—	18.38	35.7	1.599	9.9	95.2	1.74	97.2	6.5	25.5	21.2	40	66	
52	5	—	18.54	38.3	1.484	8.2	98.3	1.50	98.5	6.7	24.5	21.7	40	66	
52N	N	—	18.46	37.9	1.567	10.3	96.0	1.68	98.3	8.0	25.5	19.2	40	66	
Average		—	18.47	37.5	1.551	9.3	96.2	1.97	97.5	6.0	24.4	20.4	40	67	

HARPER ADAMS AGRICULTURAL COLLEGE, NEWPORT, SALOP.

(Sandy loam.)

53	1	34.4	16.96	43.4	1.521	9.0	99.5	2.32	98.8	8.0	24.5	20.2	55	75	
54	2	42.2	16.34	45.2	1.615	9.5	99.0	1.94	97.9	7.5	26.5	19.8	55	75	
55	3	38.0	16.72	43.9	1.578	8.4	98.9	1.32	97.1	9.5	26.5	20.2	55	75	
56	4	31.8	17.08	45.1	1.576	9.0	98.7	1.62	98.0	8.2	25.0	20.1	55	75	
57	5	27.1	17.48	45.0	1.592	8.8	99.0	2.20	99.0	6.7	26.5	20.4	55	78	
57N	N	40.5	17.28	44.2	1.555	9.2	98.2	1.96	98.2	9.5	24.5	19.9	55	70	
Average			35.7	16.92	44.5	1.576	9.0	1.88	98.1	8.0	25.8	20.1	55	76	

SECTION 1. (TABLE 4). SEASON 1925.

Five Plot Barleys.

Sample No.	Plot.	Barley.							Malt.					Market valuation by sub-committee. Shillings.	
		Yield dressed grain. Bushels per acre.	Moisture per cent.	1,000 corn weight (grams.) dry.	Nitrogen per cent. on dry.	Malting loss per cent. on dry.	Extract calculated to 448 lb. raw.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic Power. Lintner°.	Cold water extract per cent.	Barley, 448 lb., Nov., 1925.	Malt, 336 lb., Dec., 1925.	
SOUTH EASTERN AGRICULTURAL COLLEGE, WYE, KENT.															
(Loam over chalk.)															
58	1	47.4	15.98	42.3	1.386	10.5	99.4	2.12	99.2	8.0	26.5	23.3	60	70	
59	2	47.7	15.62	42.3	1.369	10.8	99.6	1.72	99.2	10.0	24.5	22.8	60	70	
60	3	46.4	15.70	42.0	1.425	11.5	98.6	2.08	99.1	11.0	27.0	23.5	60	70	
61	4	48.2	15.82	41.7	1.384	11.1	99.1	2.16	99.4	8.2	25.5	23.5	60	70	
62	5	42.2	15.86	41.2	1.358	11.6	99.0	1.88	99.0	11.5	24.5	23.3	60	70	
Average		46.4	15.80	41.9	1.384	11.1	99.1	1.99	99.2	9.7	25.6	23.3	60	70	

T. H. RAWLE, PORLOCK, SOMERSET.

(Loam over stone brash.)															
63	1	23.7	16.80	41.5	1.211	9.1	103.8	2.34	103.0	7.0	17.5	23.6		78	95
64	2	23.6	17.00	42.1	1.195	8.9	103.6	2.16	102.8	9.5	14.0	24.8		78	95
65	3	24.8	16.66	41.4	1.185	8.1	105.0	2.00	102.8	7.0	17.5	23.4		78	95
66	4	20.1	16.64	40.9	1.181	8.9	104.1	2.06	102.8	7.0	16.0	23.5		78	95
67	5	22.4	16.78	40.7	1.132	8.5	104.3	2.08	102.9	7.3	16.0	23.4		78	95
67N	N	21.4	16.84	41.3	1.204	8.5	104.3	2.12	102.9	7.5	19.0	23.1		78	95
Average	63-67	22.7	16.78	41.3	1.181	8.7	104.1	2.13	102.9	7.6	16.2	23.9		78	95

WOBBURN EXPERIMENTAL FARM, BEDS.

(Sandy loam.)															
68	1	16.6	18.48	40.1	1.908	11.8	91.4	2.18	95.7	12.0	33.5	22.7		37	58
69	2	21.2	18.72	40.9	2.114	11.5	91.0	2.90	95.1	12.0	37.0	21.0		37	58
70	3	22.9	18.58	41.9	2.044	10.6	85.0	2.98	87.7	14.5	14.5	16.8		37	Nil
71	4	24.6	17.94	41.4	2.013	9.1	82.2	2.84	82.6	12.0	14.0	14.4		37	Nil
72	5	23.6	18.34	41.6	1.955	10.6	89.6	3.00	92.2	12.5	26.0	18.6		37	58
72N	N	20.7	19.08	42.6	1.882	10.3	92.4	2.40	95.4	11.5	28.5	19.9		37	58
72P	NH ₄ Cl*	—	17.90	40.1	2.471	10.1	81.8	2.96	83.1	14.5	24.5	13.6		37	Nil
Average	68-72	21.6	18.41	41.2	2.007	10.6	87.9	2.78	90.7	12.6	25.0	18.7		37	—

ROTHAMSTED EXPERIMENTAL STATION, HARPENDEN, HERTS.

Malting Barley set, Great Knott Field (Heavy strong soil, clay with flints.)															
81	1	24.8	18.74	39.4	1.659	16.3	85.4	2.80	94.9	20.0	14.2	27.6		48	Not Malting Quality.
82	2	28.8	18.24	39.6	1.585	14.0	90.5	2.44	96.8	16.0	16.3	27.0		53	
83	3	28.7	18.74	39.9	1.597	15.3	85.8	2.24	93.8	22.0	12.6	27.2		53	
84	4	25.1	18.66	38.3	1.655	16.6	83.9	2.52	93.2	19.5	16.7	28.3		53	
85	5	23.2	18.12	39.2	1.597	14.8	88.0	2.42	95.2	21.0	13.6	29.0		53	
86	(KCl)	—	18.40	40.0	1.587	13.6	88.6	2.40	95.0	30.0	14.8	27.4		53	
87	(NH ₄ Cl)	—	18.54	40.7	1.552	13.4	88.0	2.60	93.9	26.0	11.1	28.4		53	
88	N	35.1	18.34	39.6	1.659	13.4	88.9	2.44	94.7	17.0	17.5	27.2		53	
89	double (NH ₄) ₂ SO ₄	—	18.46	38.8	1.691	13.3	84.3	2.46	89.7	15.5	16.3	23.5		52	
Average 81-85		27.6	18.5	39.3	1.619	14.6	86.7	2.48	95.0	19.7	14.7	27.8		52	

86 3 cwt. super., 155 lb. muriate of potash, 1 cwt. sulphate of ammonia per acre.

87 " " 168 lb. " " 91 lb. muriate " "

89 " " " " 2 cwt. sulphate " "

* 1 cwt. muriate of ammonia per acre.

SECTION I. (TABLE 5). SEASON 1926.

Five Plot Barleys.

Sample No.	Plot.	Barley.						Malt.						Market valuation by sub-committee. Shillings.	
		Yield bushels per acre.	Moisture per cent.	1,000 corn weight (grms.) dry.	Nitrogen per cent. on dry.	Malting loss per cent. on dry.	Extract calculated to 448 lb. raw.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic Power. Lintner°.	Cold water Extract per cent.	Barley, 448 lb., Nov., 1926.	Malt, 336 lb., Dec., 1926.	
NORFOLK EXPERIMENTAL STATION, SPROWSTON, NORWICH.															
<i>(Light Loam, overlying gravel.)</i>															
43	1	18.1	34.3	1.510	9.4	98.5	3.28	99.5	4.8	44.5	22.5	43	57		
44	2	17.6	32.0	1.561	9.9	97.5	2.92	98.5	4.8	48.5	22.4	41	56		
45	3	17.4	32.4	1.401	10.3	97.3	2.78	98.6	5.0	44.0	23.4	41	58		
46	4	17.6	32.3	1.509	10.1	97.2	2.50	98.4	6.0	43.0	23.4	41	55		
47	5	18.0	34.0	1.463	9.9	97.8	2.42	99.3	6.2	41.0	25.1	44	57		
47N	N	17.9	31.9	1.458	10.0	97.9	3.18	99.5	5.8	46.5	22.9	42	53		
Average	43—47	17.7	33.0	1.489	9.9	97.5	2.78	98.9	5.4	44.2	23.4	42	57		

HARPER ADAMS AGRICULTURAL COLLEGE, NEWPORT, SALOP.

<i>(Sandy loam.)</i>														
53	1	32.4	17.4	36.7	1.651	11.3	95.7	3.30	97.8	9.0	54.0	22.6	39	51D
54	2	41.6	16.9	37.7	1.539	11.7	97.7	3.16	99.8	5.0	54.5	21.0	40	58
55	3	40.6	17.2	37.4	1.492	12.4	95.9	3.36	99.2	5.3	48.5	21.0	40	53D
56	4	45.6	16.8	38.5	1.420	11.6	98.8	3.14	101.0	4.3	46.5	20.4	45	58
57	5	41.1	17.3	37.2	1.430	10.1	99.0	3.14	100.0	5.3	51.0	22.3	40	54
57N	N	33.3	16.3	35.3	1.553	10.8	96.8	3.24	98.5	6.3	51.5	21.8	40	54
Average	53—57	40.3	17.1	37.5	1.506	11.4	97.4	3.22	99.6	5.8	50.9	21.5	41	55

WOBURN EXPERIMENTAL FARM, BEDS.

<i>(Sandy loam.)</i>														
68	1	32.2	16.2	36.2	1.522	8.7	101.0	3.42	99.1	4.0	49.5	22.4	46	60
69	2	28.5	15.9	35.6	1.598	10.2	97.1	3.44	97.7	4.5	66.5	23.5	40	52
70	3	—	16.1	33.7	1.545	10.0	97.8	3.42	98.2	3.7	62.5	22.1	42	54
71	4	—	16.3	35.3	1.625	9.7	99.0	3.26	98.8	4.0	62.5	22.4	41	58
72	5	35.3	15.7	37.6	1.513	9.6	100.8	3.22	100.0	3.2	53.5	20.9	46	65D
73	N	39.3	16.7	34.1	1.610	8.9	99.8	3.02	98.4	4.0	62.5	21.1	39	52
74	AmCl	—	16.1	35.8	1.449	9.6	100.7	3.16	99.6	4.2	48.5	21.7	45	60D
75	Super.K. AmCl	—	16.3	36.6	1.491	8.6	101.3	3.10	99.4	3.5	53.0	20.8	41	62
Average	68—72	33.8	16.0	35.7	1.561	9.6	99.1	3.35	98.8	3.9	58.9	22.3	43	58

ROTHAMSTED EXPERIMENTAL STATION, HARPENDEN, HERTS.

Malting Barley Set, New Zealand Field

(Heavy strong soil, clay with flints.)

81	1	43.0*	17.0	38.4	1.604	9.8	98.4	3.16	98.6	5.0	50.0	22.2	40	57D
82	2	44.4*	17.0	38.8	1.711	9.9	97.6	2.92	97.9	5.2	51.1	22.2	39	54D
83	3	—	16.9	37.3	1.673	9.6	97.7	3.06	97.5	4.3	58.0	23.0	39	52
84	4	—	17.5	37.1	1.710	9.0	98.3	3.08	98.2	4.5	51.5	21.8	39	55
85	5	47.9*	17.0	38.4	1.599	9.8	98.1	2.94	98.3	5.0	55.0	22.3	41	53
86	KCl	—	17.4	36.4	1.726	9.3	97.7	3.08	97.9	4.5	53.0	22.3	39	54
87	AmCl	—	17.2	36.8	1.684	9.3	98.3	3.14	98.2	6.2	54.0	22.4	39	51
88	N	42.6*	17.0	36.9	1.683	9.8	98.0	3.50	98.2	5.3	59.5	22.9	39	57
Average	81—85	44.5*	17.1	38.1	1.659	9.6	98.0	3.03	98.1	4.8	53.2	22.3	40	54

* Measured Bushels.

SECTION I. (TABLE 6).

Five Plot Barleys.

Sample No.	Plot.	Barley.					Malt.					Market valuation by sub-committee. Shillings.		
		Moisture per cent.	1,000 corn weight (grms.) dry.	Nitrogen per cent. on dry.	Maling loss per cent. on dry.	Extract calculated to 448 lb. raw.	Moisture per cent.	Extract per 336 lb. on dry.	Colour.	Diastatic Power. Lintner°.	Cold water Extract per cent.	Barley per 448 lb.	Malt per 336 lb.	
SEASON 1927.														
NORFOLK AGRICULTURAL STATION, SPROWSTON.														
(Light loam.)														
43	1	—	19.64	39.2	1.406	8.9	97.9	3.52	100.2	4.2	44.0	21.2	56	75
44	2	—	19.52	39.4	1.400	9.2	98.5	3.64	101.4	5.2	41.0	21.2	54	75
45	3	—	18.34	40.0	1.419	9.0	98.9	3.76	100.0	3.5	50.0	21.6	52	75
46	4	—	19.70	39.8	1.350	8.1	98.8	3.34	100.4	4.0	47.0	20.4	56	75
47	5	—	19.22	39.6	1.355	9.3	98.2	3.52	101.5	4.0	46.0	20.4	60	75
47N	N	—	18.98	40.0	1.419	8.3	98.6	3.48	99.6	3.7	51.5	22.1	54	75

SEASON, 1928.

R. A. CLARKE AND SONS, CHISELBOROUGH, SOMERSET.

(Light sandy soil, loam.)

29	1	—	18.0	35.3	1.464	8.7	99.2	3.46	99.4	3.0	36.5	19.0	38	56	
30	2	—	18.4	35.7	1.428	11.1	96.9	3.26	100.2	3.5	41.0	23.1	39	58	
31	3	—	18.5	36.4	1.404	10.1	98.4	2.90	100.7	3.0	41.5	21.2	38	56	
32	4	—	18.4	33.9	1.424	10.2	98.3	2.82	100.7	3.0	41.5	21.4	39	58	
33	5	—	18.8	36.2	1.430	9.8	98.7	2.78	101.1	3.2	37.0	21.2	38	58	
33N	6	—	18.7	37.1	1.457	10.3	98.0	3.12	100.7	3.0	45.5	22.4	38	56	

Other examples of comparisons of the above manurial treatments will be found under:—

1928 Section III. Woburn, Section VII, Norfolk Agricultural Station.

1929 Woburn, Wellingore.

1930 Wellingore, Sparsholt.

1931 Rothamsted, Wellingore, Wye.

SECTION II.

LARGE MALTING BARLEY PLOTS, 2ND SERIES.
 Sulphate and Muriate of Ammonia and no Nitrogen Plots.

Manurial Treatments indicated as:—

O. No manure.

S. 1 cwt. of Sulphate of Ammonia per acre.

M. 91 lb. of Muriate of Ammonia per acre.

SEASON 1926. TABLE 7.

VARIETY: PLUMAGE-ARCHER,
EXCEPT AT CAWKWELL.

Sample No.	Manurial Treatment.	Yield in bushels per acre.	Barley.					Malt.										Market valuation by sub-committee Shillings.	
			Moisture per cent.	1,000 corn weight (grms.) dry.	Nitrogen per cent. on dry.	Making loss per cent. on dry.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic Power.	Lintner.	Cold water Extract per cent.	1,000 corn weight (grms.) dry.	Nitrogen % on dry	Total	Permanently soluble.	Barley, 448 lb., Nov., 1926.	Malt, 336 lb., Dec., 1926.	
SIR HARRY HOPE, BARNEYHILL, E. LOTHIAN.																			
(Good red soil).																			
1	O	—	16.9	39.7	1.516	7.5	3.1100.1	4.0	43.5	20.1	—	—	—	—	—	46	71		
						9.9	1.2100.2	6.5	27.2	19.6	34.1	1.45	0.49	—	—	—	80		
2	S	—	16.7	40.9	1.536	7.7	3.3100.2	4.0	42.7	19.2	—	—	—	—	—	46	72		
						10.2	1.599.5	8.5	29.5	19.4	36.0	1.57	0.50	—	—	—	85		
W. HASLER, DUNMOW, ESSEX.																			
(Medium to heavy clay loam.)																			
3	O	—	17.8	37.5	1.595	8.6	3.299.5	4.2	53.3	22.0	—	—	—	—	—	43	63		
							1.799.7	4.7	34.5	19.5	34.4	1.55	0.55	—	—	—	71		
4	O	—	17.4	36.4	1.476	8.4	3.0100.5	3.8	52.5	21.5	—	—	—	—	—	44	63		
							1.4100.4	5.7	29.0	18.7	34.8	1.45	0.53	—	—	—	69		
5	S	—	17.7	37.6	1.463	9.0	2.899.9	4.3	46.6	22.1	—	—	—	—	—	47	61		
							1.4100.2	5.0	33.9	19.9	34.5	1.50	0.52	—	—	—	69		
6	S	—	17.2	37.3	1.552	9.2	2.899.9	4.5	49.4	22.2	—	—	—	—	—	44	61D		
							1.4100.1	4.0	36.4	19.0	34.6	1.52	0.55	—	—	—	70		
Mean	O	22.8	17.6	36.9	1.535	8.5	3.1100.0	4.0	52.9	21.7	—	—	—	—	—	43	63		
	S	21.8	17.4	37.4	1.507	9.1	1.5100.0	5.2	31.7	19.1	34.6	1.50	0.54	—	—	45	70		
							2.899.9	4.4	48.0	22.1	—	—	—	—	—	—	61		
							1.4100.1	4.5	35.1	19.4	34.6	1.51	0.54	—	—	—	69		
A. E. DAVY, CAWKWELL, LINCS.*																			
(Loam over Chalk.)																			
7	O	—	18.4	29.8	1.749	10.5	2.996.3	5.3	52.9	23.7	—	—	—	—	—	38	55		
							1.395.9	4.7	34.5	18.9	28.3	1.70	—	—	—	—	60		
8	O	—	17.6	31.3	1.577	9.8	3.199.1	4.8	45.0	22.6	—	—	—	—	—	40	58D		
							1.497.6	8.5	25.0	19.4	29.7	1.56	—	—	—	—	55D		
9	S	—	17.8	30.4	1.811	9.5	3.097.6	4.5	48.3	21.8	—	—	—	—	—	38	52		
							1.296.6	4.7	42.5	19.5	28.3	1.72	—	—	—	—	56		
10	S	—	18.5	31.2	1.618	9.2	2.898.6	4.5	47.6	22.3	—	—	—	—	—	40	57		
							1.499.0	6.0	33.0	19.6	29.5	1.54	—	—	—	—	60		
Mean	O	27.6	18.0	30.5	1.663	10.1	3.097.7	5.0	48.9	23.1	—	—	—	—	—	39	56		
	S	30.5	18.1	30.8	1.714	9.3	1.396.7	6.6	29.7	19.1	29.0	1.63	—	—	—	39	57		
							2.998.1	4.5	47.9	22.0	—	—	—	—	—	—	45		
							1.397.8	5.3	37.7	19.5	28.9	1.63	—	—	—	—	58		

* Spratt-Archer seed.

SECTION II. (TABLE 7.) SEASON 1926

Large Plots. 2nd Series.

Sample No.	Manurial Treatment.	Yield in bushels per acre.	Barley.				Malt.				Nitrogen % on dry		Market valuation by sub-committee. Shillings.				
			Moisture per cent.	1,000 corn weight (grms.) dry.	Nitrogen per cent. on dry.	Maltng loss per cent. on dry.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic Power.	Lintner.	Cold water Extract per cent.	1,000 corn weight (grms.) dry.	Total	Permanently soluble.	Barley, 448 lb., Nov., 1926.	Malt, 336 lb., Dec., 1926.

G. H. NEVILLE, WELLINGORE, LINCS.

(Lincoln Heath, light loam.)

11	O	—	18.6	30.2	1.361	9.6	3.0	98.4	5.5	39.2	23.4	—	—	—	—	43	60
							1.5	100.3	2.7	35.0	19.7	30.0	1.28	0.52		42	68
12	O	—	17.1	32.3	1.432	10.5	3.1	98.3	5.0	41.7	23.2	—	—	—	—	42	53D
							1.5	99.7	6.0	26.3	19.4	30.7	1.36	0.51		45	65D
13	S	—	16.5	31.9	1.425	10.3	3.3	98.6	5.3	41.7	23.6	—	—	—	—	45	54D
							1.4	100.3	4.2	33.3	20.4	30.5	1.29	0.52		46	65D
14	S	—	17.1	34.1	1.315	10.3	3.0	98.8	5.7	43.5	23.4	—	—	—	—	46	62
							1.4	100.9	4.5	30.3	19.9	—	—	—	—	46	70
Mean	O	22.0	17.8	31.2	1.396	10.0	3.0	98.3	5.2	40.4	23.3	—	—	—	—	42	56
							1.5	100.0	4.8	30.6	19.5	30.4	1.32	0.52		45	66
	S	27.0	16.8	33.0	1.370	10.3	3.1	98.7	5.5	42.6	23.5	20.1	(30.5)	(1.29)	(0.52)	45	58
							1.4	100.6	4.3	31.8	20.1	(30.5)	(1.29)	(0.52)		45	67

R. A. CLARKE & SONS, CHISELBOROUGH, STOKE-UNDER-HAM, SOMERSET.

(Light sandy soil.)

16	O	—	17.9	36.6	1.430	7.3	2.9	100.8	3.2	46.0	19.5	—	—	—	—	58	85
							1.6	100.8	3.2	34.5	18.3	33.3	1.37	0.51		56	84
18	O	—	19.0	35.7	1.461	6.3	2.7	100.4	3.2	46.0	19.1	—	—	—	—	56	80
							1.6	100.8	4.0	27.0	18.2	33.7	1.39	0.49		55	81
20	O	—	17.7	38.6	1.414	10.0	3.1	100.7	3.2	46.0	18.9	—	—	—	—	55	80
							1.7	101.8	3.5	34.5	18.2	36.1	1.34	0.46		42	83
15	S	—	19.0	34.2	1.542	7.7	2.7	99.2	3.5	57.0	20.5	—	—	—	—	42	62
							1.3	98.8	5.7	25.0	18.3	31.9	1.50	0.48		55	70
17	S	—	18.4	34.2	1.483	7.7	2.7	100.9	3.0	46.0	18.9	—	—	—	—	55	85
							1.6	100.9	3.2	33.3	18.7	—	1.34	0.51		49	88
19	S	—	17.9	34.8	1.437	7.0	2.8	100.2	3.2	46.0	19.3	—	—	—	—	49	71
							1.9	101.1	3.2	44.0	18.3	32.9	1.40	0.47		49	81
Mean	O	33.5	18.2	37.0	1.435	7.9	2.9	100.6	3.2	46.0	19.2	—	—	—	—	56	82
							1.6	101.1	3.6	32.0	18.2	34.4	1.37	0.49		49	83
	S	39.0	18.4	34.4	1.487	7.5	2.7	100.1	3.2	49.7	19.6	(32.4)	1.41	0.49		49	73
							1.6	100.3	4.0	34.1	18.4	(32.4)	1.41	0.49		49	80

H. V. SHERINGHAM, FAKENHAM, NORFOLK.

(Medium loam.)

21	O	—	18.5	33.4	1.466	8.3	3.2	99.4	3.5	34.2	19.4	—	—	—	—	44	63
22	S	—	18.3	32.7	1.492	8.4	2.9	98.6	3.7	37.4	20.2	—	—	—	—	40	62
23	M	—	18.7	36.4	1.582	7.7	2.9	98.1	3.5	34.4	19.4	—	—	—	—	42	72

(No bulk malting.)

SECTION II. (TABLE 7). SEASON 1926.

Large Plots. 2nd Series.

Sample No.	Manurial Treatment.	Yield in bushels per acre.	Barley.					Malt.								Market valuation by sub-committee. Shillings.	
			Moisture per cent.	1,000 corn weight (grms.) dry.	Nitrogen per cent. on dry.	Making loss per cent. on dry.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Dastatic Power.	Lintner.°	Cold water Extract per cent.	1,000 corn weight (grms.) dry.	Nitrogen % on dry		Barley, 448 lb., Nov., 1926.	Malt, 336 lb., Dec., 1926.
														Total	Permanently soluble.		
25	O	—	19.2	33.2	1.424	7.6	2.9	99.7	3.3	50.5	30.2	—	32.2	1.46	0.45	40	60
							1.4	99.0	3.2	26.3	17.7	—	—	—	—	41	70
26	O	—	19.1	34.0	1.471	—	1.4	99.7	3.7	27.0	18.4	31.7	1.44	0.50	—	—	—
							3.2	99.0	4.0	55.5	21.7	—	—	—	—	38	58
27	S	—	19.5	33.8	1.603	7.8	1.2	98.2	5.5	32.8	19.0	32.2	1.53	0.53	—	—	58
							1.3	97.0	4.5	26.3	17.8	33.2	1.60	0.48	—	—	62
28	S	—	18.5	34.3	1.643	—	—	—	—	—	—	—	—	—	—	39	—
							1.4	99.3	3.4	26.6	18.0	32.0	1.45	0.48	—	40	66
							1.2	97.6	5.0	29.5	18.4	32.7	1.56	0.50	—	38	60
Mean	O	38.5	19.1	33.6	1.447	7.6	—	—	—	—	—	—	—	—	—	—	—
	S	49.5	19.0	34.0	1.623	7.8	—	—	—	—	—	—	—	—	—	—	—

NORFOLK AGRICULTURAL STATION, SPROWSTON, NORWICH.

(Sandy loam, overlaying brick earth.)

26 and 28 not malted in stocking.

J. H. SPILMAN, BEVERLEY, YORKS.

(Wold land, chalk subsoil.)

29	O	—	17.0	36.5	1.510	11.0	3.1	98.8	5.5	50.0	24.2	—	—	—	—	38	52 D
							1.2	99.5	7.0	21.7	19.4	34.0	1.46	0.47	—	37	61
30	O	—	17.2	35.0	1.483	10.2	2.9	98.1	5.3	58.5	22.5	—	—	—	—	37	52
							1.1	99.1	7.0	23.8	17.9	—	—	—	—	38	64 D
31	S	—	16.9	33.1	1.578	10.1	2.9	97.7	5.3	57.5	23.2	—	—	—	—	38	52
							1.3	99.0	9.7	19.2	19.3	33.0	1.50	0.49	—	37	61
32	S	—	17.2	32.4	1.566	9.3	2.9	96.6	4.3	61.0	21.5	—	—	—	—	37	53
							1.0	97.4	6.7	30.3	18.3	33.7	1.54	0.50	—	—	60
Mean	O	32.1	17.1	35.7	1.496	10.6	3.0	98.4	5.4	54.2	23.4	—	—	—	—	37	52
							1.1	99.3	7.0	22.7	18.6	(34.0)	(1.46)	(0.47)	—	37	62
	S	32.9	17.0	32.7	1.572	9.7	2.9	97.1	4.8	59.2	22.3	—	—	—	—	37	52
							1.1	98.2	8.2	24.7	18.8	33.4	1.52	0.50	—	—	60

W. BRUCE & SON, LONGNIDDRY, E. LOTHIAN.

(Sandy loam.)

33	O	—	17.2	37.5	1.395	7.5	3.4	101.2	3.0	50.0	19.4	—	—	—	—	44	71
							1.3	101.6	5.0	28.6	18.1	35.5	1.38	0.50	—	50	75 D
34	O	—	17.7	38.9	1.366	—	—	—	—	—	—	—	—	—	—	—	—
							1.5	102.3	3.5	30.3	17.6	35.6	1.30	0.46	—	—	79
35	S	—	17.3	35.6	1.466	7.3	3.2	99.9	3.3	58.0	20.1	—	—	—	—	42	58 D
							1.3	100.7	6.5	26.3	18.6	33.9	1.41	0.47	—	—	66
36	S	—	17.6	38.3	1.383	—	—	—	—	—	—	—	—	—	—	46	—
							1.6	101.7	3.7	40.0	18.8	—	—	—	—	—	67 D
Mean	O	48.5	17.4	38.2	1.380	7.5	1.4	101.9	4.2	29.4	17.8	35.6	1.34	0.48	—	47	77
	S	44.4	17.4	36.9	1.424	7.3	1.4	101.2	5.1	33.1	18.7	(33.9)	(1.41)	(0.47)	—	44	66

SECTION II. (TABLE 7). SEASON 1926.

Large Plots. 2nd Series.

Sample No.	Manurial Treatment.	Yield bushels per acre.	Barley.					Malt.										Market valuation by sub-committee. Shillings.		
			Moisture per cent.	1,000 corn weight (grms.) dry.	Nitrogen per cent. on dry.	Making loss per cent. on dry.	Moisture per cent.	Extract per 338 lb. dry.	Colour.	Diastatic Power.	Lintner.	Cold water Extract per cent.	1,000 corn weight (grms.) dry.	Nitrogen % on dry		Total	Permanently soluble.	Barley, 448 lb., Nov., 1926.	Malt, 336 lb., Dec., 1926.	
37	O	—	17.5	39.7	1.412	7.4	3.3	99.6	3.2	49.0	19.3	—	—	—	—	—	—	49	81	
38	O	—	17.4	41.9	1.409	7.4	2.7	98.6	3.2	48.0	19.7	—	—	—	—	—	—	53	80	
39	S	—	16.4	36.9	1.417	8.6	2.8	99.0	3.0	51.0	21.0	—	—	—	—	—	—	47	65	
40	S	—	16.9	38.4	1.369	8.9	3.1	100.4	4.0	47.0	22.1	—	—	—	—	—	—	50	60	
Mean	O	31.4	17.4	40.8	1.440	7.4	3.0	99.1	3.2	48.5	19.5	—	—	—	—	—	—	51	80	
	S	36.3	16.6	37.6	1.393	8.7	2.9	99.7	3.5	49.0	21.5	—	—	—	—	—	—	48	62	

L. MORTIMER, NYNEHEAD, SOMERSET.

(Red, light, good barley soil.)

37	O	—	17.5	39.7	1.412	7.4	3.3	99.6	3.2	49.0	19.3	—	—	—	—	—	—	49	81	
38	O	—	17.4	41.9	1.409	7.4	2.7	98.6	3.2	48.0	19.7	—	—	—	—	—	—	53	80	
39	S	—	16.4	36.9	1.417	8.6	2.8	99.0	3.0	51.0	21.0	—	—	—	—	—	—	47	65	
40	S	—	16.9	38.4	1.369	8.9	3.1	100.4	4.0	47.0	22.1	—	—	—	—	—	—	50	60	
Mean	O	31.4	17.4	40.8	1.440	7.4	3.0	99.1	3.2	48.5	19.5	—	—	—	—	—	—	51	80	
	S	36.3	16.6	37.6	1.393	8.7	2.9	99.7	3.5	49.0	21.5	—	—	—	—	—	—	48	62	

(Not malted in bulk.)

ROTHAMSTED AGRICULTURAL STATION, HARPENDEN, HERTS.

(Heavy strong soil, clay with flints.)

West Barn Field.

41	O	—	18.4	39.6	1.531	7.3	3.2	99.0	4.5	54.5	20.1	—	—	—	—	—	—	40	57D	
							1.5	99.2	5.7	27.8	17.7	36.4	1.58	0.51	—	—	—	38	57D	
42	O	—	18.6	40.6	1.624	—	1.1	98.1	5.2	28.6	17.4	35.4	1.56	0.50	—	—	—	38	62D	
43	S	—	18.1	38.1	1.751	7.0	3.1	99.1	4.3	57.0	20.5	—	—	—	—	—	—	38	58D	
							1.5	99.0	5.7	25.0	18.0	34.4	1.58	0.50	—	—	—	39	62D	
44	S	—	19.3	38.2	1.573	—	1.3	98.9	5.7	25.6	17.4	36.7	1.50	0.51	—	—	—	39	60	
Mean	O	—	18.5	40.1	1.577	7.3	1.3	98.6	5.4	28.2	17.5	35.9	1.57	0.50	—	—	—	39	59	
	S	—	18.7	38.1	1.662	7.0	1.4	98.9	5.7	25.3	17.7	35.6	1.54	0.50	—	—	—	38	61	

42 and 44 not malted in stocking.

New Zealand Field.

45	O	—	17.8	39.7	1.619	—	1.4	99.1	6.0	31.8	19.0	37.0	1.55	0.51	—	—	—	38	60	
46	S	—	17.0	36.9	1.560	—	1.3	99.2	6.0	32.3	19.6	35.6	1.56	0.53	—	—	—	39	57D	

SOUTH EASTERN AGRICULTURAL COLLEGE, WYE, KENT.

(Kent loam, overlying chalk.)

47	O	—	17.4	38.7	1.560	10.2	3.3	99.0	5.5	46.0	22.3	—	—	—	—	—	—	44	58	
48	O	—	16.2	42.2	1.592	10.8	3.4	99.3	6.3	46.5	23.0	—	—	—	—	—	—	48	58D	
49	S	—	17.4	36.6	1.567	9.8	3.6	97.3	4.3	61.5	22.1	—	—	—	—	—	—	46	53D	
50	S	—	17.3	40.2	1.572	10.1	3.2	97.6	6.3	49.0	22.9	—	—	—	—	—	—	42	58D	
Mean	O	50.5	16.8	40.4	1.576	10.5	3.3	99.1	5.9	46.2	22.6	—	—	—	—	—	—	46	58	
	S	48.3	17.3	38.4	1.569	9.9	3.4	97.4	5.3	55.2	22.5	—	—	—	—	—	—	44	55	

Not malted in bulk.

SECTION II. (TABLE 8). SEASON 1927.

Large Plots. 2nd Series.

Variety: SPRATT-ARCHER (37/6).

Sample No.	Plot No.	Manurial Treatment.	Barley.										Malt.							Market Valuation by sub-committee Shillings
			Yield in bushels per acre.			Moisture, per cent.	1,000 corn weight (grams.) dry.	Nitrogen, per cent. on dry.	Malting Loss, per cent. on dry.	Extract calculated to 448 lb. raw.	Moisture, per cent.	Extract per 336 lb. dry.	Colour.	Diastatic Power, Lintner.	Cold Water Extract, per cent.	Permanently soluble N. per cent. on dry.				
			Head Corn.	Tail Corn.	Total.															
W. BRUCE & SONS, LONGNIDDRY, E. LOTHIAN.																				
Samples from Grower, malted in stocking by H. M. Lancaster.																				
401 F	1	S/Amm.	57.2	6.7	63.9	21.4	34.0	1.55	8.5	95.0	3.3	99.1	4.5	48.0	20.6	—	46	72		
404 F	4	„	60.4	6.2	66.6	20.9	32.5	1.55	8.1	95.6	3.6	98.7	3.7	48.5	19.6	—	44	72		
402 F	2	Nil	58.2	3.6	61.8	20.5	35.3	1.43	8.1	98.1	3.6	100.6	2.7	44.5	19.0	—	50	72		
405 F	5	„	62.2	3.2	65.2	20.6	35.1	1.48	7.5	98.2	3.5	100.3	3.7	47.5	20.2	—	47	72		
403 F	3	M/Amm.	63.0	4.4	67.4	20.9	33.0	1.61	8.1	95.4	3.4	98.5	4.2	53.0	20.2	—	45	72		
406 F	6	„	64.3	4.1	68.4	20.7	33.0	1.56	8.1	96.0	3.5	98.8	4.0	47.5	19.2	—	45	72		

Screened samples, as malted in bulk, malted in stocking by H. M. Lancaster.

401/4 B	1 & 4	S/Amm.	—	—	—	21.1	32.1	1.58	8.6	94.5	2.6	98.3	3.0	54.0	18.7	—	72
402/5 B	2 & 5	Nil	—	—	—	20.5	36.5	1.46	7.9	97.0	2.7	100.1	2.7	53.5	18.4	—	72
403/6 B	3 & 6	M/Amm.	—	—	—	20.8	34.3	1.51	7.5	96.3	2.8	98.6	3.0	54.0	18.4	—	72

Screened bulked samples, malted commercially by Messrs. Wm. Younger & Co.

401/4 B	1 & 4	—	—	—	—	—	—	—	—	—	1.9	98.9	4.3	39.0	18.8	—	76
402/5 B	2 & 5	—	—	—	—	—	—	—	—	—	1.8	100.8	6.0	39.5	19.2	—	74
403/6 B	3 & 6	—	—	—	—	—	—	—	—	—	1.4	100.1	5.0	39.5	19.0	—	76

G. H. NEVILLE, WELLINGORE, Lincs.

(Lincoln Heath, Light loam.)

Samples from Grower, malted in stocking by H. M. Lancaster.

407	1	S/Amm.	59.7	3.0	62.7	19.9	35.0	1.46	7.9	99.2	3.3	100.7	5.0	39.5	18.7	—	47
410	4	"	62.1	5.7	62.8	20.5	36.8	1.46	8.6	98.6	3.2	101.7	5.5	40.5	21.3	—	59
408	2	Nil	52.2	3.0	55.2	18.0	37.0	1.39	8.5	102.3	3.2	102.3	5.3	45.5	22.1	—	63
411	5	"	56.7	4.4	61.1	18.7	38.2	1.33	8.9	101.8	3.2	103.1	4.7	43.0	21.6	—	68
409	3	M/Amm.	59.6	6.5	66.1	18.6	35.8	1.39	8.4	101.8	3.4	102.4	5.0	48.5	22.5	—	59
412	6	"	57.7	4.5	62.2	18.1	38.4	1.35	8.3	103.1	3.3	103.2	4.0	45.5	21.5	—	61

MAJOR BUXTON, KING'S LYNN, NORFOLK.

Samples prepared for commercial malting, malted in stocking by H. M. Lancaster.

413 S	—	S/Amm.	—	—	—	18.3	34.6	1.42	9.3	99.5	3.0	100.8	3.5	63.0	19.0	—	80
414 S	—	Nil	—	—	—	18.1	34.5	1.59	8.3	99.9	2.7	99.8	4.0	64.0	19.3	—	80
415 S	—	S/Amm. + Potash	—	—	—	18.2	34.1	1.50	9.5	99.0	2.6	100.3	4.0	58.5	19.4	—	80
416 S	—	S/A + Potash + Super.	—	—	—	19.2	34.2	1.40	9.0	99.1	2.6	101.1	4.5	54.5	19.4	—	80

Barleys as above, malted commercially by Messrs. Hugh Baird & Sons.

413 B	—	—	—	—	—	—	—	—	—	—	2.5	101.5	5.7	40.0	20.2	0.52	82
414 B	—	—	—	—	—	—	—	—	—	—	2.7	101.8	6.3	43.5	20.5	0.55	82
415 B	—	—	—	—	—	See above.	—	—	—	—	2.4	101.8	6.5	43.5	21.1	0.56	82
416 B	—	—	—	—	—	—	—	—	—	—	2.4	101.5	4.7	45.0	21.4	0.54	82

NORFOLK AGRICULTURAL STATION, SPROWSTON, NORWICH.

(Light loam, overlying gravel.)

Samples prepared for commercial malting, malted in stocking by H. M. Lancaster.

417 S	—	S/Amm.	{ 35.0	1.0	36.0	14.4	34.5	1.34	8.4	106.3	2.7	101.8	3.8	36.0	20.2	—	—
418 S	—	Nil	{ 38.5	1.1	39.6	14.4	34.5	1.34	8.4	106.3	2.7	101.8	3.8	36.0	20.2	—	—
			{ 35.0	1.0	36.0	14.4	34.5	1.34	8.4	106.3	2.7	101.8	3.8	36.0	20.2	—	—
			{ 32.5	0.7	33.2	14.9	34.1	1.41	8.6	104.2	2.7	100.7	4.0	30.0	20.4	—	—

Barleys as above, malted commercially by Messrs. Hugh Baird & Sons.

417 B	—	S/Amm.	—	—	—	—	—	—	—	—	2.2	102.0	5.3	40.0	20.5	0	—
418 B	—	Nil	—	—	—	—	—	—	—	—	2.2	100.9	5.5	43.0	20.1	0	—

SECTION II. (TABLE 9). SEASON 1928.

Large Plots. 2nd Series.

VARIETY: SPRATT-ARCHER (37/6)

Sample No.	Plot No.	Manurial Treatment.	Yield in bushels per acre.		Barley.						Malt.						Market valuation by sub- o'ttee, Shillings.	
			Head Corn.	Tail Corn.	Total.	Moisture, per cent.	1,000 corn weight (grams) dry.	Nitrogen, per cent. on dry.	Malting Loss, per cent. on dry.	Extract calculated to 448 lb. raw.	Moisture, per cent.	Extract per 336 lb. dry.	Colour.	Diastatic PowerLinter. °	Cold Water Extract, per cent.	Permanently soluble N, per cent. on dry.	Barley, per 448 lb.	Malt, per 336 lb.

W. BRUCE & SONS, LONGNIDDRY, E. LOTHIAN.

(Sandy loam.)

Samples from Grower, malted in stocking by H. M. Lancaster.

401 F	1	S/Amm. ..	58.0	9.1	65.1	17.8	37.1	1.52	10.3	99.7	3.5	101.2	3.0	50.0	23.6	mean 0.486	38	55
404 F	4	S/Amm. ..	61.0	9.4	70.4	17.1	37.6	1.58	10.8	98.8	3.4	100.2	2.5	60.0	23.0		38	55
402 F	2	Nil ..	58.0	6.0	62.0	18.7	37.0	1.56	10.8	96.8	3.3	100.1	3.2	57.5	21.6	—	38	55
405 F	5	„ ..	60.0	6.4	66.4	17.7	36.7	1.51	10.5	100.0	3.5	101.8	2.5	55.0	22.6	—	38	55
403 F	7	M/Amm. ..	62.0	9.4	71.4	17.6	37.6	1.56	10.8	98.4	3.5	100.4	3.0	56.0	23.0	0.488	38	55
406 F	6	„ ..	58.0	7.0	65.0	17.0	36.7	1.39	10.6	100.9	3.3	102.0	3.0	45.5	24.0	0.464	38	55

Sweated samples, as malted commercially, malted in stocking by H. M. Lancaster.

The Malting Losses and calculated Extracts based on original Moistures.

401 BSL	1	S/Amm. ..	—	—	—	12.6	—	—	9.3	99.2	3.5	99.7	2.5	53.0	22.7	mean 0.492	—	55
404 BSL	4	„ ..	—	—	—	11.6	—	—	10.3	98.1	3.3	99.3	2.5	56.5	21.4		—	55
402 BSL	2	Nil ..	—	—	—	12.4	—	—	9.7	97.1	3.4	99.8	2.8	55.5	22.5	—	—	55
405 BSL	5	„ ..	—	—	—	12.2	—	—	9.3	99.5	3.2	100.2	3.0	48.5	20.0	—	—	55
403 BSL	3	M/Amm. ..	—	—	—	12.5	—	—	9.7	98.5	3.1	99.4	3.0	52.0	21.2	0.491	—	55
406 BSL	6	„ ..	—	—	—	11.7	—	—	9.9	101.4	3.3	101.8	2.8	44.5	22.1	0.468	—	55

Sweated samples, as above, malted in stocking by J. S. Ford

401 BSF	1	S/Amm. ..	—	—	—	—	—	—	—	—	1.8	98.5	4.7	35.5	19.2	0.477	—	55
404 BSF	4	„ ..	—	—	—	—	—	—	—	—	1.8	99.4	4.0	36.5	18.6	0.464	—	55
402 BSF	2	Nil ..	—	—	—	See above.				—	2.3	98.6	3.8	38.0	18.6	0.467	—	55
405 BSF	5	„ ..	—	—	—					—	2.1	100.3	6.7	40.5	19.0	0.462	—	55
403 BSF	3	M/Amm. ..	—	—	—	—	—	—	—	—	1.8	99.2	4.3	40.5	19.1	0.483	—	55
406 BSF	6	„ ..	—	—	—	—	—	—	—	—	1.6	101.8	6.2	37.0	19.2	0.456	—	55

Sweated barley, as above, malted commercially by Messrs. Wm. Younger & Co.

401 B	1	S/Amm. ..	—	—	—	—	—	—	—	—	3.1	98.9	3.7	41.5	17.8	0.484	—	55
404 B	4	„ ..	—	—	—	—	—	—	—	—	2.4	99.1	3.7	39.5	17.5	0.463	—	55
402 B	2	Nil ..	—	—	—	See above.				—	3.1	99.0	3.3	44.0	17.9	0.488	—	55
405 B	5	„ ..	—	—	—					—	2.7	99.9	4.5	36.0	17.9	0.453	—	55
403 B	3	M/Amm. ..	—	—	—	—	—	—	—	—	2.6	99.0	3.5	42.0	17.7	0.477	—	55
406 B	6	„ ..	—	—	—	—	—	—	—	—	2.3	101.3	5.2	36.0	18.5	0.467	—	55

SECTION II. (TABLE 9). SEASON 1928.

Large Plots. 2nd Series.

Sample No.	Plot No.	Manurial Treatment.	Yield in bushels per acre.			Barley.						Malt.						Market valuation by sub-ottee, Shillings
			Head Corn.	Tail Corn.	Total.	Moisture, per cent.	1,000 corn weight (grams.)	Nitrogen, per cent. on dry.	Maltng Loss, per cent. on dry.	Extract calculated to 448 lb. raw.	Moisture, per cent.	Extract per 336 lb. dry.	Colour.	Diastase Power, Lintner°.	Cold Water Extract, per cent.	ermanently soluble N, per cent. on dry.	Barley per 448 lb.	

G. H. NEVILLE, WELLINGORE, Lincs.

(Lincoln Heath, light loam.)

Samples from Grower, malted in stocking by H. M. Lancaster.

407 F	1	S/Amm.	50.0	3.0	53.0	18.8	34.6	1.62	9.6	97.4	3.5	99.5	2.5	43.0	22.8	—	46	58
410 F	4	"	50.8	2.1	52.9	17.1	34.9	1.58	10.3	100.0	3.4	100.8	2.5	46.0	23.0	—	46	58
408 F	2	Nil	52.1	1.7	53.8	17.8	35.4	1.48	10.0	100.2	3.2	101.6	2.8	41.0	23.7	—	46	58
411 F	5	"	51.9	1.7	53.6	16.6	35.7	1.44	9.5	101.1	3.1	101.7	2.3	39.5	23.0	—	46	58
409 F	3	M/Amm	55.3	2.6	57.9	17.0	34.8	1.64	11.5	97.9	3.3	100.0	3.0	49.5	25.9	—	46	58
412 F	6	"	53.1	2.7	55.8	17.8	34.7	1.57	9.9	99.1	3.2	100.4	2.5	44.0	23.5	—	46	58

Bulked samples prepared for commercial malting, malted in stocking by H. M. Lancaster.

407 10 BS	1 & 4	S/Amm.	—	—	—	15.3	—	1.58	10.0	99.2	3.5	100.7	2.5	42.0	21.2	—	—	58
408 11 BS	2 & 5	Nil	—	—	—	15.2	—	1.49	10.0	100.3	3.5	100.9	2.5	37.5	22.0	0.50	—	58
409 12 BS	3 & 6	M/Amm.	—	—	—	14.9	—	1.59	10.2	98.7	3.4	99.8	2.3	43.0	23.6	—	—	58

Barleys as above, malted commercially by Messrs. Hugh Baird & Son.

407 10 B	1 & 4	S/Amm.	—	—	—	—	—	—	—	—	3.4	100.4	3.0	38.0	19.6	0.50	—	58
408 11 B	2 & 5	Nil	—	—	—	—	—	See above.	—	—	2.6	101.6	2.7	35.0	19.6	0.48	—	58
409 12 B	3 & 6	M/Amm.	—	—	—	—	—	—	—	—	2.6	101.2	2.8	37.0	19.2	0.50	—	58

G. ANDREW, FITZHEAD, MILVERTON, SOMERSET.

(Red loam.)

Samples from Grower, malted in stocking by H. M. Lancaster.

425 F	2	S/Amm.	46.0	6.5	52.5	17.8	40.4	1.53	10.1	99.7	3.3	101.2	3.0	46.0	22.3	—	41	61
428 F	5	"	50.7	5.8	56.5	17.3	41.5	1.60	10.2	100.0	3.3	101.0	3.0	54.0	23.0	—	41	61
426 F	1	Nil	40.9	4.0	44.9	19.0	40.6	1.62	10.2	97.7	3.5	100.7	3.2	48.0	23.5	0.51	41	61
429 F	4	"	46.6	4.6	51.2	18.3	39.8	1.51	10.2	99.7	3.3	101.9	3.2	44.0	24.5	0.54	41	61
427 F	3	M/Amm.	50.9	5.0	55.9	18.5	41.9	1.64	9.8	99.1	3.3	100.9	3.3	54.0	24.0	—	41	61
430 F	6	"	54.6	6.7	61.3	17.8	40.6	1.55	10.7	99.2	3.5	101.3	3.0	51.5	24.8	—	41	61

Bulked and Sweated samples prepared for commercial malting, malted in stocking by H. M. Lancaster.

425/8 BS	2 & 5	S/Amm.	—	—	—	12.7	—	—	10.0	100.1	3.3	101.0	3.3	45.5	24.2	—	—	—
426/9 BS	1 & 4	Nil	—	—	—	12.2	—	—	9.9	99.6	3.7	101.9	2.3	47.5	22.9	0.52	—	—
427/30 BS	3 & 6	M/Amm.	—	—	—	11.2	—	—	9.5	100.0	3.2	101.3	3.0	46.5	22.3	—	—	—

Barleys as above, malted commercially by Messrs. James D. Taylor & Sons, Bath.

425/8 B	2 & 5	S/Amm.	—	—	—	—	—	—	—	—	2.6	100.5	3.5	45.5	18.9	0.48	—	63
426/9 B	1 & 4	Nil	—	—	—	—	—	See above.	—	—	2.5	100.9	3.5	37.0	19.0	0.49	—	63
427/30 B	3 & 6	M/Amm.	—	—	—	—	—	—	—	—	2.4	100.9	3.5	40.0	18.8	0.51	—	62

SECTION III.

SMALL REPLICATED PLOTS, MANURIAL EXPERIMENTS—SECOND SERIES.

TABLE 10. SEASON 1927.

ROTHAMSTED. GREAT HARPENDEN FIELD, 1927.

COMPARISON OF NITROGENOUS FERTILISERS, Sulphate and Muriate of Ammonia, Urea and Cyanamide, each used in single and double dressings. Effect of Superphosphate.

A				B			
2U P	2M P	2C	0(b)	0(a)	0(b) P	2S P	1S P
1M P	1C	2S	1S	1U	2C P	2U	2M
0(a) P	0(d) P	1U P	0(c)	1M	1C P	0(c) P	0(d)
2U	0(a)	0(d)	2C P	0(a) P	2C	2S	0(d) P
0(b) P	0(c) P	1S P	1M	1S	2U P	0(b)	1M P
1U	1C P	2S P	2M	2M P	1C	1U P	0(c)
C				D			

SYSTEM OF REPLICATION.—4 randomised blocks of 12 plots each.

Area of plot $\frac{1}{2}$ acre.

0.—No Nitrogen.

U, C, S, M.—Nitrogen in form of Urea, Cyanamide, Sulphate and Muriate of Ammonia.

1, 2—Single and double dressings at the rate of 1 and 2 cwt. per acre. 8/Amn or its equivalent.

P—Superphosphate at the rate of 5 cwt. per acre. Manures applied March 28-29.

Barley sown April 4-6, harvested Sept. 6-7.

VARIETY—Spratt-Archer (37/6)

Blocks.	0(a)	0(b)	0(c)	0(d)	1U	1C	1S	1M	2U	2C	2S	2M
<i>Actual Weights in lb.—Total Grain.</i>												
A	35.5	23.25	32.5	39.125	42.0	45.625	35.125	53.875	60.0	46.625	36.625	67.75
B	33.5	37.125	31.25	29.875	42.875	51.5	58.875	45.75	62.25	55.375	67.0	65.25
C	34.375	43.0	34.625	30.25	50.125	53.625	44.875	46.0	59.375	49.375	58.0	67.75
D	30.5	32.375	33.375	28.5	48.563	51.125	51.625	56.625	64.0	49.5	50.0	63.0

<i>1,000 Corn Weights on dry Barley.</i>												
A	35.7	35.4	34.2	35.0	35.4	35.3	34.8	37.2	36.6	34.1	34.6	36.1
B	36.3	36.0	36.6	35.5	37.2	36.1	36.3	36.0	35.9	36.4	34.6	37.0
C	36.1	36.8	36.6	36.2	36.6	36.1	35.7	36.5	35.6	35.9	35.2	34.4
D	36.2	36.2	36.1	34.8	36.6	35.7	35.4	36.6	35.3	36.0	33.9	36.5

<i>Nitrogen per cent. on dry Barley.</i>												
A	1.48	1.42	1.49	1.48	1.45	1.48	1.47	1.49	1.51	1.52	1.51	1.49
B	1.43	1.44	1.48	1.48	1.60	1.55	1.41	1.46	1.52	1.54	1.44	1.50
C	1.46	1.46	1.49	1.45	1.46	1.49	1.46	1.44	1.55	1.52	1.51	1.56
D	1.46	1.42	1.45	1.42	1.40	1.46	1.46	1.45	1.48	1.49	1.49	1.50

Mean moisture percentage 20.0.

SUMMARY OF RESULTS.

	No Nitro- gen	Single Dressing.				Double Dressing.				All Nitrogen treatments.		
		S/Amn	M/Amn	Cyan.	Urea	S/Amn	M/Amn	Cyan.	Urea	Stand. Error	Mean.	Stand Error
		Yield in bushels per acre.										
Without phosphate ..	22.2	31.0	32.8	34.6	33.2	31.0	47.6	34.4	43.4	2.42	31.4	0.70
With phosphate ..	25.0	37.0	39.4	37.6	32.4	44.6	46.6	37.4	44.2		35.0	
Mean of plots with and without phosphate ..	23.6	34.0	36.2	36.0	32.8	37.8	47.0	35.8	43.8	1.70	33.2	

SECTION III. (TABLE 10), SEASON 1927.

REPLICATED PLOTS. Rothamsted, 1927. Summary.—*contd.*

	No Nitro- gen	Single Dressing				Double Dressing				All Nitrogen treatments.		
		S/Amm	M/Amm	Cyan.	Urea	S/Amm	M/Amm	Cyan.	Urea	Stand. Error	Mean	Stand. Error
1,000 Corn weight (grams) dry.												
Without phosphate ..	35.8	35.1	36.2	35.5	36.9	34.2	35.7	35.0	35.8		35.6	
With phosphate ..	36.0	36.0	36.9	36.1	36.0	34.9	36.3	36.2	36.0		36.3	
Mean of plots with and without phosphate ..	35.9	35.6	36.6	35.8	36.4	34.6	36.0	35.6	35.9		36.0	
Nitrogen, per cent. on dry.												
Without phosphate ..	1.46	1.46	1.45	1.47	1.53	1.50	1.53	1.50	1.54		1.50	
With phosphate ..	1.46	1.44	1.47	1.52	1.43	1.48	1.50	1.53	1.50		1.48	
Mean of plots with and without phosphates ..	1.46	1.45	1.46	1.50	1.48	1.49	1.51	1.52	1.52	0.018	1.49	

Significant response in yield to superphosphate, and large response to single and double nitrogen. No yield differences between different nitrogenous manures appear in the single dressings, but the double dressing gives no further increase with cyanamide, and very little with ammonium sulphate. Forms of nitrogen had no significant effects on thousand corn weight or nitrogen percentage. On the average double nitrogen dressings gave a nitrogen percentage significantly above single dressings and no nitrogen.

SELECTED BARLEY'S MALTED.

Sample No.	Plot	Manurial Treat- ment	Barley					Malt					Market valuation by sub-com- mittee.	
			Moisture per cent	1,000 corn weight (grams) dry	Nitrogen per cent on dry	Malting Loss per cent on dry	Extract calcu- lated to 448lb raw	Moisture per cent	Extract per 336 lb dry	Colour	Dia- static Power, (unitners)	Cold Water Extract per cent	Barley per 448 lb	Malt per 336 lb
502	A8	1S.	21.0	34.8	1.47	8.8	95.2	3.2	99.1	4.0	39.5	21.7	41	68
503	A7	2S.	21.1	34.6	1.51	8.8	94.2	3.3	98.1	4.7	41.0	21.7	39	68
504	B9	1M.	20.7	36.0	1.46	8.6	95.8	3.4	99.1	4.0	46.0	20.8	38	68
505	C12	2M.	21.0	34.4	1.56	8.5	91.1	3.2	97.7	4.3	47.0	21.9	41	68
518	A11	1U.P.	20.7	35.4	1.45	8.5	95.3	3.1	98.5	4.0	47.5	21.3	39	68
519	A1	2U.P.	20.4	36.6	1.51	8.4	96.3	3.4	99.1	4.3	50.0	21.7	38	68
506	A6	1C.	18.9	35.3	1.48	9.5	96.4	3.3	98.5	5.0	43.5	21.6	39	68
507	A3	2C.	19.4	34.1	1.52	9.2	96.0	3.3	98.4	3.5	45.0	21.5	40	68
501	B1	O.	18.7	36.3	1.43	11.5	95.5	3.4	99.6	4.2	43.5	21.4	38	68
511	A10	O.P.	20.9	35.0	1.48	8.6	95.4	3.2	99.1	4.0	37.5	20.6	40	68

SECTION III. (TABLE 11). SEASON 1928.
ROTHAMSTED. LONG HOOS FIELD. 1928.

COMPARISON OF NITROGENOUS FERTILISERS, Sulphate and Muriate of Ammonia, Urea and Cyanamide, each used in single and double dressings. EFFECT OF SUPERPHOSPHATE

A												B											
1S	0	1U	0	0	1C	2C	2U	2M	1M	2S	0	1M	2S	2M	1S	0	2C	0	0	0	1U	1C	2U
P	(a)		(c)	(b)	P	P				P	(d)	P		P		(c)	P	(a)	(b)	(d)	P	P	P
C												D											
2M	0	0	2U	2C	1U	1C	0	0	1M	1S	2S	2U	0	1M	1S	1U	0	1C	2S	0	2C	2M	0
P	(c)	(a)	P		P		(b)	(d)	P				(a)		P		(c)	P	P	(b)	P		(d)
E												F											
2M	0	0	1U	0	2C	2U	1C	1M	1S	2S	0	2M	1S	2C	0	0	0	2S	2U	1C	0	1U	1M
	(a)	(b)		(c)	P		P	P	P	P	(d)		P	P	(c)	(d)	(a)	P		P	(b)		
G												H											
0	1M	2C	0	2M	1U	0	2S	2U	1S	0	1C	0	1C	2U	1U	0	2M	1S	0	2C	1M	0	2S
(c)	P		(d)	P	P	(a)		P		(b)		(c)	P	P	P	(d)	P		(a)		P	(b)	

SYSTEM OF REPLICATION.—8 Randomised Blocks of 12 plots each. Area of plot $\frac{1}{8}$ acre. 0=No Nitrogen; U, C, S, M=Nitrogen in form of Urea, Cyanamide, Sulphate and Muriate of Ammonia, 1, 2=Single and double dressings at the rate of 1 and 2 cwt. per acre, S/Ammonia, or its equivalent; P=Superphosphate at the rate of 3 cwt. per acre. Variety, Spratt-Archer. Manures applied March 28th. Barley sown March 28th, harvested August 24th

ACTUAL WEIGHTS IN LB.—TOTAL GRAIN.

Block.	Without Phosphate.		With Phosphate.		1S	1M	1C	1U	2S	2M	2C	2U
	0(a)	0(b)	0(c)	0(d)								
A	47.5	43.5	47.0	32.75	64.5	44.25	49.0	53.25	45.75	46.25	58.5	58.25
B	29.5	32.5	28.0	32.75	36.25	37.5	41.25	41.25	35.0	43.0	47.5	38.0
C	36.75	38.25	53.5	42.25	53.5	56.75	43.0	48.75	57.25	54.0	45.5	37.0
D	42.0	44.0	43.25	40.75	53.75	49.5	48.25	56.0	56.0	49.5	52.75	56.5
E	44.75	45.75	49.25	36.75	56.25	54.5	57.75	57.5	55.75	65.5	66.5	63.75
F	35.5	40.0	40.5	41.0	45.25	45.5	46.5	43.0	45.5	54.5	51.5	45.25
G	40.0	35.0	44.0	36.25	45.0	51.25	42.75	50.0	46.5	53.75	47.0	53.0
H	39.25	40.75	37.25	41.25	43.5	48.0	46.0	42.75	46.0	53.5	51.0	49.75

1000 Corn weight (grams) dry.

A	39.2	38.2	39.6	36.9	40.3	36.9	38.9	41.7	36.8	38.0	38.7	39.0
B	38.3	37.8	36.6	37.4	37.2	37.9	37.1	38.8	37.6	37.8	36.8	37.4
C	36.8	37.3	36.8	36.9	37.6	38.0	36.8	38.2	36.4	36.9	35.8	37.9
D	37.6	38.4	37.4	36.7	36.8	36.6	36.8	37.8	36.5	38.8	38.2	36.7
E	40.7	40.0	39.8	38.7	37.2	39.0	39.7	39.6	36.7	39.0	39.5	38.2
F	38.0	39.5	37.3	38.6	38.4	36.8	35.8	37.5	38.9	38.7	37.7	35.2
G	39.5	37.6	39.0	38.2	39.2	37.2	37.2	38.1	38.7	38.6	36.4	38.9
H	38.6	37.3	38.3	39.6	37.8	39.4	37.4	37.5	35.5	37.0	37.8	37.6

Nitrogen per cent. on dry.

A	1.92	1.85	1.84	1.93	2.06	1.87	1.86	1.92	2.05	2.04	1.93	1.93
B	1.88	1.92	1.85	1.93	1.99	1.93	2.02	1.97	2.13	2.11	2.10	2.22
C	1.88	1.89	2.11	1.90	2.07	2.01	2.07	2.07	2.22	2.19	2.18	2.07
D	1.94	1.98	1.97	1.96	2.06	2.00	2.01	2.08	2.23	2.25	2.13	2.13
E	1.82	1.73	1.77	1.95	2.03	2.01	1.97	1.80	2.09	2.02	1.81	1.98
F	1.93	1.96	1.94	1.91	2.07	2.06	2.08	2.07	2.13	2.14	2.13	2.18
G	2.09	1.98	2.07	1.94	2.04	2.21	1.92	2.10	2.28	2.13	2.16	2.22
H	1.94	2.01	1.92	1.97	2.07	2.07	2.00	2.04	2.25	2.18	2.18	2.14

Mean Moisture percentage 17.9

SECTION III. (TABLE 11). SEASON 1928.
ROTHAMSTED, REPLICATED PLOTS.

	No Nitro- gen.	Single Dressing.				Double Dressing.				All nitrogen treatments.			
		S/Amm	M/Amm	Cyan.	Urea.	S/Amm	M/Amm	Cyan.	Urea.	S.E.	Mean.	S.E.	
Yield in bushels per acre.													
Without phosphate ..	28.4	31.8	34.6	30.8	37.4	33.0	38.6	34.2	40.0	1.68	32.8	0.48	
With phosphate ..	28.8	39.2	34.6	36.0	32.6	36.2	36.4	41.0	31.8		33.6		
Mean of plots with and without phosphate ..	28.6	35.6	34.6	33.4	35.0	34.6	37.4	37.6	35.8	1.18	33.2	—	
1000 Corn weight (grams) dry.													
Without phosphate ..	38.4	38.0	37.3	37.1	39.2	37.0	38.6	36.7	37.3	0.50	37.9	0.14	
With phosphate ..	38.0	38.1	38.1	37.8	38.2	37.2	37.6	38.5	38.0		38.0		
Mean of plots with and without phosphate ..	38.2	38.0	37.7	37.4	38.7	37.1	38.1	37.6	37.6	0.35	37.9	—	
Nitrogen per cent. on dry.													
Without phosphate ..	1.92	2.04	1.98	2.01	1.97	2.22	2.12	2.15	2.06	0.031	2.02	0.009	
With phosphate ..	1.94	2.06	2.06	1.99	2.04	2.13	2.15	2.00	2.16		2.03		
Mean of plots with and without phosphate ..	1.93	2.05	2.02	2.00	2.01	2.17	2.13	2.08	2.11	0.022	2.02	—	

BULKED SAMPLES OF EACH TREATMENT MALTED.

		Barley.					Malt.					Market valuation by sub-committee. Shillings.		
Sample No.	Manurial Treatment.	Moisture per cent.	1,000 corn weight (grams) dry	Nitrogen per cent. on dry	Maltng loss per cent. on dry	Extract calculated to 448 lb. raw.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic power. Lintner.	Cold water extract per cent.	Perm. soluble nitrogen per cent. on dry.	Barley, per 448 lb.	Malt, per 336 lb.
Without Phosphate.														
501	No Nitrogen	17.9	38.4	1.92	13.3	90.2	3.0	95.6	6.0	54.5	24.0	0.61	37.	37.
502	1. S/Amm.	18.1	38.0	2.04	12.8	90.6	3.4	95.3	3.8	60.0	23.0		37.	37.
503	2. S/Amm.	18.1	37.1	2.22	14.7	85.9	3.2	93.9	5.5	69.0	24.2	0.70	37.	37.
504	1. M/Amm.	18.1	37.3	1.98	13.9	87.3	3.2	93.4	6.0	56.5	24.2		37.	37.
505	2. M/Amm.	18.6	38.6	2.12	—	—	—	—	—	—	—		37.	37.
506	1. Cyan.	18.1	37.1	2.00	13.0	89.9	3.2	94.9	5.0	60.0	24.0		37.	37.
507	2. Cyan.	18.1	36.7	2.15	13.5	87.8	3.3	93.2	5.3	73.0	23.2		37.	37.
508	1. Urea	18.0	39.2	1.97	—	—	—	—	—	—	—		37.	37.
509	2. Urea	17.9	37.3	2.06	—	—	—	—	—	—	—		37.	37.
With 3 cwt. Superphosphate per acre.														
511	No Nitrogen	17.9	37.9	1.94	13.8	89.4	3.3	95.9	4.8	63.0	24.0	0.65	37.	37.
512	1. S/Amm.	18.0	38.2	2.06	13.2	89.4	3.2	94.6	4.0	68.0	22.9		37.	37.
513	2. S/Amm.	18.2	37.2	2.13	14.0	88.3	3.4	94.4	4.8	68.5	23.2	0.69	37.	37.
514	1. M/Amm.	18.0	38.1	2.06	12.7	89.7	3.2	94.2	4.3	65.5	23.2		37.	37.
515	2. M/Amm.	17.8	37.6	2.15	—	—	—	—	—	—	—		37.	37.
516	1. Cyan.	17.7	37.8	1.98	12.3	90.9	3.1	94.8	4.0	61.5	22.2		37.	37.
517	2. Cyan.	17.8	38.5	2.00	12.6	90.3	3.2	94.6	4.0	59.0	23.1		37.	37.
518	1. Urea	17.5	38.2	2.04	—	—	—	—	—	—	—		37.	37.
519	2. Urea	17.2	38.0	2.16	—	—	—	—	—	—	—		37.	37.

SECTION III. (TABLE 12). SEASON 1928.

WOBURN. BUTT CLOSE, 1928.

EFFECT OF NITROGENOUS POTASSIC AND PHOSPHATIC FERTILISERS.

A								B							
N	N K	N P	O	N K P	K	K P	P	O	N K P	K P	K	N P	N	P	N K

SYSTEM OF REPLICATION: 4 randomised blocks of 8 plots each.
Area of plot: $\frac{1}{8}$ th acre.
TREATMENTS:
O = No manure.
Sulphate of Ammonia (N) at the rate of 1 cwt. per acre; Sulphate of Potash (K) at the rate of 14 cwt. per acre, and Superphosphate (P) at the rate of 3 cwt. per acre, in all combinations.
Manures applied April 19th.
Barley sown, March 17th. Harvested August 9th.
VARIETY: "Spratt-Archer."

C								D							
N K	O	N	N K P	P	N P	K P	K	O	K	N P	N K P	N K	P	K P	N

Block.	O	P	N	K	NP	KP	NK	NKP
<i>Actual weights in lb.—Total grain.</i>								
A	43.25	37.25	61.25	78.75	55.5	43.25	67.25	31.25
B	34.0	61.25	48.0	57.0	38.75	66.0	64.0	57.25
C	42.0	41.5	47.0	55.75	43.75	44.0	45.25	42.5
D	23.25	52.25	77.75	53.75	60.5	59.75	46.5	53.25
Bulked Samples numbered	68	74	72N	73	70	72	71	69

<i>1,000 corn weight (grms.) dry.</i>								
A	35.6	34.4	36.6	35.9	35.1	34.6	35.8	35.4
B	35.0	36.6	36.2	35.6	36.4	36.4	36.6	34.9
C	36.6	37.4	36.3	38.2	36.5	36.8	37.8	36.3
D	37.7	37.6	36.6	38.0	37.8	38.7	37.8	36.9

<i>Nitrogen per cent. on dry.</i>								
A	1.26	1.20	1.29	1.26	1.29	1.22	1.33	1.26
B	1.29	1.38	1.34	1.42	1.36	1.45	1.38	1.38
C	1.33	1.32	1.31	1.48	1.31	1.34	1.37	1.36
D	1.39	1.28	1.43	1.39	1.63	1.30	1.30	1.40

Market Valuation by Sub-committee, 48s. per 448 lb. for each; only irregularly distributed minor differences noted.
Mean moisture percentage 18.6.

SUMMARY OF RESULTS.

	O	P	N	K	NP	KP	NK	NKP	Stand- ard Error	Mean.
Yield in bushels per acre ..	25.4	34.4	41.8	43.8	35.4	38.0	39.8	33.0	4.10	36.4
1,000 corn weight (grams) dry ..	36.2	36.5	36.4	36.9	36.4	36.6	37.0	35.9	—	36.5
Nitrogen per cent. on dry ..	1.32	1.30	1.34	1.39	1.40	1.33	1.35	1.37	0.036	1.35

Significant interaction of the nitrogenous and potassic fertilizers. In the absence of one, the other increased the yield significantly, but, in the presence of one, there was no effect due to the adding of the other. Manuring produced no significant differences in nitrogen content.

None were malted.

SECTION III. (TABLE 13). SEASON 1928.

ROTHAMSTED. LONG HOOS FIELD. 1928.

NITROGENOUS TOP DRESSING, NITROCHALK.

I.				II.				III.				IV.			
B	A	C	D	C	B	D	A	A	C	D	B	D	A	B	C

TREATMENTS:

A = No Top Dressing.
 B = Early Top Dressing of Nitrochalk, May 22nd.
 C = Middle Top Dressing of Nitrochalk, June 4th.
 D = Late Top Dressing of Nitrochalk, June 19th.
 Rate of application = 2 cwt. per acre.

SYSTEM OF REPLICATION:—4 randomised blocks of 4 plots each.

Area of each plot = $\frac{1}{16}$ acre.

Barley sown, March 28th, harvested August 24th, 1928.

Variety: "Standwell."

Block.		Total Grain.				Nitrogen per cent. on dry.			
		Actual weights in lbs							
		A	B	C	D	A	B	C	D
I.	..	36.0	35.5	39.0	41.25	2.23	2.17	2.24	2.19
II.	..	43.5	41.75	39.25	39.0	2.14	2.14	2.13	2.23
III.	..	45.5	51.5	51.75	48.0	2.05	2.00	2.08	2.09
IV.	..	49.0	43.5	54.75	47.75	1.94	2.10	1.99	2.12

Mean moisture percentage—18.2

SUMMARY OF RESULTS.

Average Yield.	No Top Dressing.	Early Top Dressing.	Middle Top Dressing.	Late Top Dressing.	Standard Error.	Mean
Grain, bushels per acre	..	31.0	30.8	33.0	31.4	31.6
1,000 corn weight (grams) dry	..	46.5	46.1	45.9	46.4	46.2
Nitrogen per cent. on dry	..	2.09	2.10	2.11	2.16	2.12

No significant response to treatment in yield. Late top dressing gave significantly higher percentage of nitrogen in dry matter of grain than the control.

BULKED SAMPLES OF EACH TREATMENT MALTED.

Sample No.	Manurial Treatment	Barley.						Malt.						Market Valuation by Sub-committee. Shillings.	
		Moisture per cent.	1000 corn weight (grams) dry.	Nitrogen per cent. on dry.	Malting loss per cent. on dry.	Extract calculated to 448 lb. raw.	Moisture per cent.	Extract per 336 lb dry.	Colour.	Diastatic Power Lintner?	Cold Water Extract per cent.	Permanently soluble Nitrogen per cent on dry.	Barley per 448 lb.	Malt per 336 lb.	average
491	A	18.7	46.5	2.09	12.8	91.4	3.1	96.9	7.8	55.0	22.0	74	39	53	
492	B	18.5	46.1	2.10	12.6	91.8	3.1	96.5	8.7	54.0	23.4	74	39	53	
493	C	17.8	45.9	2.11	13.1	92.2	3.4	96.9	6.5	59.0	22.6	74	39	53	
494	D	18.0	46.4	2.16	13.1	92.1	3.2	97.1	7.0	58.5	23.0	74	39	53	

SECTION III. (TABLE 14). SEASON 1929.
ROTHAMSTED. LONG HOOS FIELD, 1929.

COMPARISON OF NITROGENOUS FERTILISERS, Sulphate and Muriate of Ammonia, Urea and Cyanamide, each used in single and double dressings. Effect of Superphosphate and Sulphate of Potash.

A. SINGLE DRESSING.

I	N	C	O	M	S
II	O	M	S	C	N
III	S	O	C	N	M
IV	M	S	N	O	C
V	C	N	M	S	O

B. DOUBLE DRESSING.

I	N	U	M	S	C
II	S	C	N	M	U
III	M	S	U	C	N
IV	C	N	S	U	M
V	U	M	C	N	S

SYSTEM OF REPLICATION: 2 Latin Squares.

AREA OF EACH PLOT: $\frac{1}{2}$ acre.

Testing Sulphate (S) and Muriate (M) of Ammonia, Cyanamide (C), Urea (U) and Nitrate of Soda (N).

RATES: 0.2 and 0.4 cwt. of N per acre. Single Urea replaced by No Nitrogen.

Each Plot divided into 4 sub-plots each $\frac{1}{16}$ acre, for the treatments—(1) No Potash or Phosphate, (2) Sulphate of Potash (.6 cwt. K_2O per acre), (3) Superphosphate (.4 cwt. P_2O_5 per acre), (4) Sulphate of Potash and Superphosphate. Yields of sub-plots estimated by sampling method only.

Barley sown. March 12th. Harvested August 10th.

VARIETY: "Plumage-Archer" (3.4 bushels per acre). Manures applied: March 14th-16th.

Previous Crop: Barley.

		Single Dressing.					Double Dressing.				
Row.		O	S	M	C	N	U	S	M	C	N
<i>Actual Weights in lb. per Whole Plot.</i>											
I		51.50	64.50	62.25	56.75	75.50	64.25	59.50	66.00	63.00	79.25
II		59.00	59.75	57.50	66.50	71.25	69.75	77.00	69.50	71.75	77.00
III		55.75	66.25	75.25	69.75	64.50	75.50	71.50	82.75	75.50	72.75
IV		63.00	61.75	66.50	75.00	76.50	66.00	77.50	69.50	79.25	80.50
V		51.50	71.25	68.75	63.00	71.25	80.25	67.75	78.75	78.50	80.25
<i>1000 Corn weight (grams) dry.</i>											
I	O	39.9	38.5	38.0	39.3	38.0	39.2	34.5	38.1	35.2	37.7
	K	38.1	37.6	39.3	37.8	37.7	37.6	34.5	38.1	37.0	35.7
	P	37.0	37.5	39.0	40.8	36.8	35.2	33.9	37.9	36.5	38.7
	PK	38.5	38.6	39.0	38.0	39.5	35.4	33.3	39.1	37.8	35.8
II	O	39.2	36.7	38.9	39.4	37.7	37.9	36.5	37.6	38.7	37.3
	K	39.4	39.1	37.3	40.5	37.0	38.2	37.5	36.0	37.5	38.3
	P	39.1	38.6	37.5	40.3	39.5	37.8	37.7	37.1	37.4	37.2
	PK	40.0	39.3	40.5	39.0	39.1	37.2	38.3	38.3	39.1	37.1
III	O	38.6	39.8	40.0	40.2	40.5	40.8	40.3	41.2	38.3	37.8
	K	40.2	40.0	40.3	40.2	37.9	38.0	37.9	39.0	40.7	36.8
	P	41.6	43.1	41.0	39.4	39.3	37.8	37.5	41.5	38.7	38.3
	PK	39.3	38.6	41.3	41.2	39.1	38.8	37.9	42.5	38.8	37.7
IV	O	39.6	41.2	40.7	40.6	40.2	40.0	39.3	39.3	38.1	38.9
	K	40.6	39.3	38.9	37.9	39.8	38.9	37.9	39.3	40.6	37.8
	P	39.6	39.6	38.9	40.6	42.3	39.6	36.8	39.8	39.3	37.9
	PK	41.6	40.5	38.9	39.5	39.3	40.5	38.6	38.6	40.6	38.7
V	O	42.7	40.7	41.5	41.5	37.3	35.6	36.0	38.3	37.6	38.2
	K	40.2	40.3	42.1	41.7	38.9	36.6	37.0	37.9	37.7	37.1
	P	38.8	42.3	41.5	38.9	38.6	36.1	38.0	38.1	37.7	38.5
	PK	39.8	39.8	40.8	39.7	37.0	38.0	36.3	38.7	38.8	36.5

SECTION III. (TABLE 14). SEASON 1929.

Rothamsted Replicated Plots.

		Single Dressing.					Double Dressing.				
Row		O	S	M	C	N	U	S	M	C	N
<i>Nitrogen per cent. on dry.</i>											
I	O	1.40	1.63	1.36	1.37	1.46	1.44	1.56	1.46	1.53	1.46
	K	1.36	1.38	1.48	1.33	1.38	1.34	1.41	1.41	1.55	1.59
	P	1.48	1.36	1.43	1.27	1.47	1.38	1.35	1.46	1.57	1.45
	PK	1.41	1.52	1.38	1.31	1.50	1.34	1.37	1.49	1.48	1.55
II	O	1.47	1.40	1.47	1.44	1.36	1.41	1.43	1.43	1.51	1.56
	K	1.45	1.40	1.40	1.48	1.38	1.42	1.60	1.44	1.40	1.60
	P	1.44	1.46	1.40	1.47	1.52	1.41	1.40	1.46	1.49	1.46
	PK	1.40	1.47	1.36	1.41	1.47	1.43	1.46	1.47	1.44	1.53
III	O	1.41	1.55	1.47	1.53	1.47	1.64	1.56	1.66	1.56	1.62
	K	1.54	1.47	1.45	1.54	1.52	1.52	1.46	1.40	1.47	1.47
	P	1.46	1.43	1.58	1.46	1.52	1.57	1.56	1.39	1.57	1.55
	PK	1.48	1.42	1.52	1.49	1.46	1.68	1.46	1.54	1.42	1.50
IV	O	1.40	1.46	1.50	1.72	1.57	1.52	1.52	1.51	1.44	1.59
	K	1.47	1.41	1.47	1.50	1.42	1.42	1.46	1.60	1.47	1.56
	P	1.53	1.45	1.47	1.57	1.55	1.56	1.49	1.62	1.40	1.48
	PK	1.44	1.44	1.44	1.56	1.49	1.61	1.52	1.53	1.58	1.65
V	O	1.59	1.50	1.56	1.58	1.42	1.55	1.49	1.36	1.46	1.44
	K	1.47	1.53	1.60	1.46	1.57	1.46	1.58	1.60	1.38	1.59
	P	1.47	1.41	1.59	1.56	1.47	1.52	1.55	1.44	1.53	1.57
	PK	1.60	1.48	1.48	1.59	1.40	1.54	1.53	1.55	1.37	1.56

Mean Moisture percentage—14.2.

SECTION III. (TABLE 14 Continued.) SEASON 1929. Rothamsted Replicated Plots.
Each Treatment marked separately.

Sample No.	Manurial Treatment.		Barley.					Malt.					Market Valuation by Sub-Committee. Shillings.	
	Nitrogenous Manure N per acre.	Other Manure per acre.	Moisture per cent.	1,000 corn wt. (gms.) dry.	Nitrogen per cent. on dry.	Making loss per cent. on dry.	Extract calculated to 448 lbs. raw.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic power.	Cold Water Extract per cent.		Perny. Soluble Nitrogen per cent. on dry.
1	None	None	14.2	40.0	1.46	9.3	102.9	3.5	99.1	3.5	41.0	22.1		35
2	"	1½ cwt. Sul Pot.	14.3	39.7	1.46	9.6	101.9	3.4	98.6	4.0	39.5	22.1		35
3	"	2 cwt. Super.	14.3	39.2	1.48	8.8	103.0	3.2	98.8	4.0	37.0	21.4		35
4	"	Potash and Super.	14.1	39.8	1.47	9.1	102.9	3.5	98.8	3.5	36.5	21.3		35
5	0.2 cwt. as S Amm.	None	14.4	39.4	1.51	8.4	102.8	3.1	98.3	4.0	40.0	21.2		35
6	"	1½ cwt. Sul Pot.	14.5	39.3	1.44	8.4	103.4	3.5	98.6	3.8	39.0	21.7		35
7	"	2 " Super.	14.2	40.2	1.42	8.8	102.7	3.2	98.4	4.0	34.5	22.4		35
8	"	Potash and Super.	14.4	39.4	1.47	9.1	103.5	3.5	99.3	3.2	39.0	21.5		35
9	"	M/Amm.	14.4	39.8	1.47	9.1	102.5	3.3	98.8	3.8	35.0	21.1		35
10	"	Potash	14.4	39.6	1.48	12.7 ?	98.9*	3.3	99.3	3.7	39.0	21.2		35
11	"	Super.	14.4	39.6	1.50	8.8	103.0	3.4	98.9	3.7	40.0	21.1		43
12	"	Potash and Super.	14.3	40.3	1.44	7.5	105.3	3.2	99.6	3.8	38.5	20.6		43
13	"	None	13.7	40.2	1.53	9.3	103.1	3.5	98.7	4.3	40.5	21.1		35
14	"	Potash	13.8	39.6	1.46	8.2	104.2	3.5	98.7	3.3	42.5	21.7		35
15	"	Super.	13.7	40.0	1.46	8.6	104.6	3.4	99.4	4.5	42.0	21.7		35
16	"	Potash and Super.	13.7	39.5	1.47	8.8	103.8	3.1	98.9	4.2	40.5	21.8		35
17	"	Nitrate of Soda	14.5	38.7	1.46	9.3	101.5	3.7	98.1	4.0	41.0	22.1		35
18	"	Potash	14.2	38.3	1.46	9.0	102.2	3.7	98.1	3.8	41.5	22.0		35
19	"	Super.	14.3	39.3	1.51	9.0	102.5	3.3	98.6	3.8	39.5	20.6	0.37	35
20	"	Potash and Super.	14.6	38.6	1.47	9.0	102.4	3.4	98.8	4.0	39.0	22.0	0.44	43
21	0.2 cwt. N. as Urea	None	14.3	38.7	1.51	8.5	102.9	3.4	98.3	3.3	40.0	21.5	0.39	43
22	"	Potash	14.2	37.9	1.44	8.1	104.3	3.1	99.4	3.8	39.0	20.2	0.40	43
23	"	Super.	14.2	38.3	1.49	8.1	103.5	3.1	99.4	3.8	39.0	20.2	0.40	43
24	"	Potash and Super.	14.2	38.0	1.54	7.8	104.0	3.6	98.5	3.0	41.5	21.6		43
25	0.4 cwt. " S. Amm.	None	14.7	37.3	1.49	8.5	103.3	3.3	99.2	3.5	41.0	22.2		43
26	"	Potash	14.6	37.0	1.50	9.1	102.4	3.3	98.9	4.0	39.5	21.4		42
27	"	Super.	14.9	36.8	1.47	8.8	102.0	3.3	98.5	4.0	42.0	21.6		42
28	"	Potash and Super.	14.8	36.9	1.47	9.0	102.1	3.3	98.7	3.8	42.0	22.4		54
29	"	None	13.9	38.9	1.48	8.1	104.6	3.4	99.1	3.3	41.5	21.2		42
30	"	Potash	14.0	38.1	1.49	8.1	104.2	3.4	98.8	3.0	42.0	21.7		43
31	"	Super.	13.7	38.9	1.48	9.3	104.3	3.3	99.1	4.0	39.5	21.4		43
32	"	Potash and Super.	13.7	39.4	1.52	8.6	104.1	3.0	98.9	3.5	42.0	21.3		43
33	"	None	14.2	37.6	1.50	8.7	103.2	3.6	98.8	4.0	40.0	22.6		41
34	"	Potash	14.3	38.7	1.46	7.6	103.9	3.4	98.8	3.8	40.0	21.3		42
35	"	Super.	14.2	37.9	1.51	7.7	104.6	3.4	99.2	3.5	38.0	21.7		42
36	"	Potash and Super.	14.1	39.0	1.46	8.3	104.7	3.4	99.0	3.5	38.5	22.2	0.42	54
37	"	None	14.4	38.0	1.54	8.7	102.8	3.6	98.6	4.0	43.5	22.4		54
38	"	Nitrate of Soda	14.3	37.1	1.56	9.0	102.7	3.5	98.7	4.0	42.5	22.7		54
39	"	Potash	14.2	38.1	1.50	8.7	103.1	3.4	98.7	4.0	42.5	22.2	0.42	42
40	"	Potash and Super.	14.3	37.2	1.56	9.0	103.1	3.6	99.1	4.0	42.0	22.0		44

SECTION III. (TABLE 14 Continued). SEASON 1929. Rothamsted Replicated Plots.
SUMMARY OF RESULTS.

	Single Dressing.						Double Dressing.						Mean	Standard Error		
	O	S	M	C	N	Std. Error	Mean	Standard Error	U	S	M	C			N	Std. Error
Yields in bushels per acre. (Sampling Method).																
No potash or phosphate	39.0	50.8	48.4	45.8	47.0	2.80	46.2	2.80	51.6	52.0	53.6	59.2	56.6	2.52	54.6	1.14
Potash ..	43.0	41.0	45.2	47.6	50.4	2.80	45.4	2.80	47.4	48.4	55.2	53.0	53.2	2.52	51.4	1.14
Phosphate ..	43.0	48.6	47.8	38.2	32.0	2.80	46.0	2.80	50.0	58.2	51.0	55.2	59.2	2.52	54.8	1.14
Potash and phosphate	40.2	48.6	46.8	45.0	48.2	2.80	45.8	2.80	50.2	49.6	51.6	52.6	54.4	2.52	51.6	1.14
Mean ..	41.4	47.2	47.0	44.2	49.4	1.14	45.8	1.14	49.8	52.0	52.8	55.0	55.8	1.06	53.0	0.88
Yields by usual Threshing Method.																
No potash or phosphate	40.2	46.2	47.2	47.2	51.2	1.76	46.2	1.76	50.8	50.4	52.4	52.6	55.6	0.88	51.6	0.88
Potash ..	39.7	39.6	39.8	39.8	38.6	0.20	39.5	0.20	38.0	37.0	38.8	38.3	37.6	0.39	37.9	0.39
Phosphate ..	39.7	39.6	39.8	39.8	38.6	0.20	39.5	0.20	38.0	37.0	38.8	38.3	37.6	0.39	37.9	0.39
Potash and phosphate	39.7	39.6	39.8	39.8	38.6	0.20	39.5	0.20	38.0	37.0	38.8	38.3	37.6	0.39	37.9	0.39
Mean ..	39.7	39.6	39.8	39.8	38.6	0.20	39.5	0.20	38.0	37.0	38.8	38.3	37.6	0.39	37.9	0.39
1000 (Corn Weight (grams) dry.																
No potash or phosphate	1.46	1.51	1.47	1.53	1.46	0.015	1.47	0.015	1.49	1.48	1.49	1.48	1.54	0.021	1.50	0.021
Potash ..	1.46	1.44	1.48	1.46	1.46	0.015	1.46	0.015	1.44	1.50	1.45	1.46	1.56	0.021	1.49	0.021
Phosphate ..	1.48	1.42	1.50	1.46	1.51	0.015	1.47	0.015	1.49	1.47	1.48	1.51	1.50	0.021	1.49	0.021
Potash and phosphate	1.46	1.47	1.44	1.47	1.46	0.015	1.46	0.015	1.54	1.47	1.52	1.46	1.56	0.021	1.51	0.021
Mean ..	1.46	1.46	1.47	1.48	1.47	0.015	1.47	0.015	1.49	1.48	1.49	1.48	1.54	0.021	1.50	0.021
Nitrogen per cent. on dry.																
No potash or phosphate	1.46	1.51	1.47	1.53	1.46	0.015	1.47	0.015	1.49	1.48	1.49	1.48	1.54	0.021	1.50	0.021
Potash ..	1.46	1.44	1.48	1.46	1.46	0.015	1.46	0.015	1.44	1.50	1.45	1.46	1.56	0.021	1.49	0.021
Phosphate ..	1.48	1.42	1.50	1.46	1.51	0.015	1.47	0.015	1.49	1.47	1.48	1.51	1.50	0.021	1.49	0.021
Potash and phosphate	1.46	1.47	1.44	1.47	1.46	0.015	1.46	0.015	1.54	1.47	1.52	1.46	1.56	0.021	1.51	0.021
Mean ..	1.46	1.46	1.47	1.48	1.47	0.015	1.47	0.015	1.49	1.48	1.49	1.48	1.54	0.021	1.50	0.021
Valuation by Sub-Committee. Shillings per 448 lbs.																
No potash or phosphate	35	35	35	35	35	0.35	35	0.35	43	42	43	41	42	0.42	42	0.42
Potash ..	35	35	35	35	35	0.35	35	0.35	43	42	43	42	42	0.42	42	0.42
Phosphate ..	35	35	35	35	35	0.35	35	0.35	43	42	43	42	42	0.42	42	0.42
Potash and phosphate	35	35	35	35	35	0.35	35	0.35	43	42	43	42	42	0.42	42	0.42
Mean ..	35	35	35	35	35	0.35	35	0.35	43	42	43	42	42	0.42	42	0.42

Significant response in yield to single dressing of Nitrogenous Fertilisers. Nitrate of Soda gives significantly higher yield than others, in both single and double dressings. In single dressing, Nitrate of Soda significantly depresses the 1,000 corn weight. In presence of double Nitrogenous dressing, Potash reduces the yield significantly.

SECTION III. (TABLE 15). SEASON 1929.

WOBURN EXPERIMENTAL STATION. *Butt Furlong Field, 1929.*COMPARISON OF NITROGENOUS FERTILISERS: Sulphate and Muriate of Ammonia.
POTASSIC FERTILISER: Sulphate of Potash.
SUPERPHOSPHATE.

B				D			
M K	M K P	K	S K P	M K P	K P	K	M K
P	M	S	S K	S K	S	S P	S K P
O	S P	K P	M P	M	O	M P	P
S K P	S	M	M K P	M K P	K P	K	S
S P	K P	K	O	M K	S K	O	M
P	M P	M K	S K	M P	S P	S K P	P
A				C			

SYSTEM OF REPLICATION: 4 randomised blocks of 12 plots each.

AREA OF EACH PLOT: $\frac{1}{16}$ acre.
O=No Manure.Sulphate (S) or Muriate (M) of Ammonia at the rate of 0.2 cwt. of Nitrogen per acre; Sulphate of Potash (K) at the rate of 0.6 cwt. K₂O per acre, and Superphosphate (P) at the rate of 0.4 cwt. Phosphoric acid per acre, in all combinations.

Manures applied: March 22nd.

Barley sown March 21st. Harvested Aug. 1st-3rd.

VARIETY: Plumage-Archer (3 bushels per acre).
Previous Crop: Sugar Beet.*Actual Weights in lb.—Total Grain.*

Blocks.	O	P	K	K+P	S	S+P	S+K	S+K +P	M	M+P	M+K	M+K +P
A	47.75	52.75	53.00	55.50	60.50	54.50	56.50	52.00	60.75	64.50	64.75	54.50
B	52.50	51.00	68.00	66.75	63.25	54.25	60.00	60.50	59.50	59.50	63.50	67.25
C	35.75	40.00	43.00	41.75	34.50	43.75	47.25	44.50	37.25	50.00	47.25	51.00
D	52.50	35.75	62.00	62.75	59.50	59.00	62.50	43.00	54.25	53.25	58.75	62.00

1,000 Corn Weight (Grams), Dry.

A	36.6	35.6	36.9	35.7	33.8	32.6	34.7	31.7	34.4	36.7	37.7	34.3
B	31.6	34.7	40.5	41.1	33.8	32.1	36.6	39.1	33.7	34.0	37.5	38.9
C	33.5	35.3	35.6	33.6	34.5	34.9	36.1	34.2	35.2	36.4	35.8	34.7
D	36.0	36.5	41.4	38.9	37.0	36.1	37.1	38.5	34.5	35.1	42.5	38.5

Nitrogen per cent. on Dry.

A	1.86	1.76	1.86	1.89	1.95	1.91	1.86	1.96	1.91	1.94	1.95	1.97
B	1.87	1.69	2.19	2.05	1.93	2.25	1.76	1.77	1.90	2.04	1.75	1.79
C	1.92	1.59	1.91	1.90	1.71	1.92	2.03	1.97	1.85	1.85	1.97	2.02
D	1.87	1.49	1.69	1.73	1.90	1.98	1.97	1.42	1.96	2.13	1.40	1.83

All valued at 30/- per 448 lb. (Blocks A, B, C, D, bulked.)

Manurial Treatment.	Nil.	P	K	PK	S	SP	SK	SPK	M	MP	MK	MPK
Samples numbered (dist. by block letters)	41	48	47	45	46	43	44	42	52	50	51	49
Yield, bushels per acre . . .	50.4	48.0	60.6	60.8	58.4	56.6	60.6	53.6	56.8	60.8	62.8	62.8
1,000 corn weight (grams) dry	34.4	35.5	38.6	37.3	34.8	33.9	36.1	35.9	34.5	35.6	38.4	36.6
Nitrogen per cent. on dry	1.88	1.63	1.91	1.89	1.87	2.02	1.90	1.78	1.90	1.99	1.77	1.90

Mean Moisture Percentage 14.0 (Air Dried).

SECTION III. (TABLE 15). SEASON, 1929.

Woburn Replicated Plots.

(b) SUMMARY OF SIGNIFICANT RESULTS.—AVERAGING FOR PHOSPHATE.

	Grain—bushels per acre.		
	No Nitrogen.	S/Amm.	M/Amm.
No Potash ..	49 2	57 4	58 8
Sulphate of Potash	60 6	57 0	62 8

Standard Error—1 6 bushels.
Mean—57 6 bushels.

	1,000 corn weight (grams) dry.			Nitrogen per cent. on dry		
	No Nitrogen	S/Amm	M/Amm	No Nitrogen.	S/Amm	M/Amm
No Potash ..	35 0	34 4	35 0	1 76	1 94	1 94
Sulphate of Potash	38 0	36 0	37 5	1 90	1 84	1 84
Standard Error	..	0 68	..	Standard Error	..	0 042
Mean ..	..	36 0	..	Mean ..	..	1 87

Significant response to Nitrogenous and Potassic fertilisers, but no response to Phosphate. The interaction of Nitrogen and Potash is significant. In the absence of one fertiliser, the other increases the yield and Nitrogen percentage significantly, but in the presence of one, no further significant effect is produced by adding the other, though a lowering of the Nitrogen percentage is indicated. The yield appears to respond better to Muriate than to sulphate, and the 1,000 corn weight to be decreased by Sulphate but not by Muriate, but these differences fall short of significance.

TWO SAMPLES MALTED. (Blocks A—D bulked)

Sample No.	Manurial Treatment.	Barley						Malt.						Market valuation by Sub-Committee. Shillings.	
		Moisture per cent.	1,000 corn weight (grams) dry.	Nitrogen per cent. on dry.	Making loss per cent. on dry.	Extract calculated to 448 lb. raw.	Moisture per cent.	Extract per 336 lb. on dry.	Colour.	Diastatic Power.	Lumner Cold Water Extract per cent.	Permanently Soluble N. per cent. on dry.	Barley, per 448 lb.	Malt, per 336 lb.	
42	S+K+P	14 0	35 9	1 78	7 0	102 9	3 1	96 6	5 0	60 0	23 3	—	30	52	
45	K+P	14 0	37 3	1 89	7 0	102 5	3 1	96 2	5 5	64 0	23 8	—	30	52	

Valuer's comment. Poor mild ale malt. No. 45 riper, sunnier, better filled

SECTION III. (TABLE 16.) SEASON 1929.
G. H. NEVILLE, ESQ., WELLINGORE, Lincs. 1929.
Effect of Sulphate of Ammonia, Sulphate of Potash and Superphosphate.

A	NK	NPK	O	NP	N	PK	P	K
B	O	K	NPK	N	NP	P	NK	PK

VARIETY : Plumage-Archer.

SOIL : Light loam on Lincoln Heath.

SYSTEM OF REPLICATION : 2 randomised blocks of 8 plots each.

AREA OF EACH PLOT : $\frac{1}{60}$ th acre.

TREATMENTS : Sulphate of Ammonia (N) at the rate of 1 cwt. per acre, Superphosphate (P) at the rate of 3 cwt. per acre, and Sulphate of Potash (K) at the rate of 1½ cwt. per acre, in all combinations.

Manures applied : March 14th.

Barley sown : March 12th. Harvested : August 22nd-23rd.

The plots were harvested by the sampling method, 20 separate metres of drill being selected at random from each plot.

Block.		O	K	N	P	KN	KP	NP	NKP
<i>Actual weights in grams per sample.</i>									
Grain A	..	729	807	736	749	822	661	859	911
B	..	796	873	848	716	852	723	966	1128
<i>1,000 corn weight (grams) dry.</i>									
A	..	36.1	36.6	36.8	36.5	37.0	36.5	37.7	38.0
B	..	37.2	36.9	36.9	37.7	38.2	37.5	37.0	37.0
<i>Nitrogen per cent. on dry.</i>									
A	..	1.48	1.42	1.43	1.44	1.48	1.43	1.56	1.50
B	..	1.38	1.44	1.43	1.42	1.48	1.46	1.47	1.41

Mean Moisture percentage—13.4 (air dried)

SUMMARY OF RESULTS.

	Yield in bushels per acre.				1,000 corn weight (grams) dry.				Nitrogen per cent. on dry.			
	Without K.		With K.		Without K.		With K.		Without K.		With K.	
	With- out N.	With N.	With- out N.	With N.	With- out N.	With N.	With- out N.	With N.	With- out N.	With N.	With- out N.	With N.
Without P	37.6	39.0	41.4	41.2	36.7	36.9	36.8	37.6	1.43	1.43	1.43	1.48
With P	36.0	44.8	34.0	50.2	37.1	37.4	37.0	37.5	1.43	1.52	1.44	1.46
Standard Error ..	1.78				0.44				0.026			
Mean	40.4				37.1				1.46			

Significant response in yield to the Nitrogenous dressing, which, however, only shows up on the plots having Superphosphate. Superphosphate depresses the yield on the plots without Nitrogenous fertiliser, but increases the yield significantly on the plots having a Nitrogenous dressing in addition. There is evidence of a small response in the aggregate to Potash, but the difference is not significant. Neither Superphosphate nor Potash affect the 1,000 corn weight or Nitrogen percentage significantly, but if the means of all the plots without Nitrogen are compared with the means of all those with Nitrogen the latter show a small significant increase in Nitrogen percentage and an increase in 1,000 corn weight which just fails to reach the 5% level of significance.

SECTION III. (TABLE 16.) SEASON 1929. WELLINGORE REPLICATED PLOTS.

EACH PAIR OF DUPLICATE SAMPLES MIXED FOR MALTING.

Sample No.	Manurial Treatment.	Barley.						Malt.							Market valuation by sub-committee. Shillings.	
		Moisture, per cent.	1,000 orn weight (grams) dry	Nitrogen, per cent. on dry.	Malting Loss, per cent on dry.	Extract cal- culated to 448lb raw.	Moisture, per cent.	Extract per 336 lb. dry	Colour.	Diastatic power. Lintner.	Cold Water Extract, per cent.	Permanently Sol. N., per cent on dry.	Barley per 448 lb	Malt per 336 lb		
54	O	13.2	36.7	1.43	8.8	104.0	3.1	98.7	3.5	37.0	20.3	0.49	45	52		
55	NPK	13.4	37.5	1.46	9.0	103.7	3.3	98.6	3.5	38.5	20.6	—	45	52		
56	NP	13.5	37.4	1.52	9.0	103.2	3.3	98.2	3.5	37.5	21.5	0.53	45	52		
57	NK	13.1	37.6	1.48	8.8	104.6	2.9	98.9	4.5	34.0	20.3	—	45	52		
58	PK	13.4	37.0	1.44	9.1	104.6	3.4	99.0	4.0	38.0	20.7	—	43D	52		
59	N	13.5	36.9	1.43	8.6	103.9	3.0	98.5	4.5	33.5	20.5	—	43D	52		
60	K	13.3	36.8	1.43	9.0	104.4	2.9	99.2	4.0	32.5	21.4	—	45	52		
61	P	13.6	37.1	1.43	8.3	104.5	3.2	99.1	3.7	38.5	21.2	—	45	52		

SECTION III. (TABLE 17.) SEASON 1929.
MR. J. M. TEMPLEMAN, FARM INSTITUTE, SPARSHOLT, WINCHESTER.

EFFECT OF CHLORIDES.

I.	O	M/Pot	100 Salt	300 Salt
II.	100 Salt	300 Salt	O	M/Pot
III.	300 Salt	100 Salt	M/Pot	O
IV.	M/Pot	O	300 Salt	100 Salt

LATIN SQUARE: Plots $\frac{1}{25}$ acre.

SOIL: Thin flinty loam on chalk.

TREATMENT: Salt at rate of 100 lb. and 300 lb. per acre
and Muriate of Potash at the rate of 1 cwt. per acre.

VARIETY: Plumage-Archer.

Barley sown, April 5th. Harvested, August 13th.

Row.	1,000 corn weight (grams) dry.				Nitrogen per cent. on dry.			
	O	M/Pot.	100 lb. salt.	300 lb. salt.	O	M/Pot.	100 lb. salt.	300 lb. salt.
I. . . .	40.0	40.3	41.1	42.2	1.31	1.27	1.29	1.31
II. . . .	40.8	41.6	40.4	41.4	1.26	1.31	1.30	1.31
III. . . .	41.3	41.0	40.9	40.8	1.26	1.27	1.31	1.39
IV. . . .	41.0	39.9	40.1	41.9	1.32	1.43	1.37	1.33

Mean Moisture percentage—15.9.

SUMMARY OF RESULTS.

	No Manure.	Muriate of Potash.	Salt 100 lb.	Salt 300 lb.	Stan- dard Error.	Mean.
Yield in bushels per acre	47.8	47.0	48.2	48.8	1.48	48.0
1,000 corn weight (grams) dry	40.3	40.7	40.6	41.6	0.24	40.9
Nitrogen per cent. on dry	1.29	1.32	1.32	1.34	0.014	1.32
Market valuation by sub-committee, shillings per 448 lb.	48	48	48	48	—	48
Bulked samples numbered	62	63	64	65		

Both 1,000 corn weight and Nitrogen percentage are slightly but significantly raised by the addition of the larger amount of Salt.
No significant effect on yield

SECTION III. (TABLE 18). SEASON 1930.

ROTHAMSTED. LONG HOOS.

COMPARISON OF NITROGENOUS FERTILISERS, Sulphate and Muriate of Ammonia, Nitrate of Soda and Cyanamide.

I.	C	S	N	M	O	<p>SYSTEM OF REPLICATION: Latin Square. AREA OF EACH PLOT: $\frac{1}{10}$th acre TREATMENTS</p> <p>O = No Nitrogen. S = Sulphate of Ammonia. M = Muriate of Ammonia. N = Nitrate of Soda C = Cyanamide.</p> <p>at the rate of 0.4 cwt. N. per acre.</p> <p>All manures applied Feb. 28th, except Cyanamide, which was sown Mar 3rd Drilled, Feb. 28th. Harvested, Aug. 15th Variety, Plumage-Archer. Previous crop Sugar Beet (tops eaten off by sheep)</p>
II.	N	O	S	C	M	
III.	S	N	M	O	C	
IV.	M	C	O	N	S	
V.	O	M	C	S	N	

Row.	O	S	M	N	C
<i>Actual Weight in lb.</i>					
I. ..	47.25	70.50	65.75	69.50	62.50
II. ..	67.00	72.25	64.75	68.00	64.25
III. ..	58.75	69.00	70.75	81.50	57.75
IV. ..	60.50	63.50	69.25	65.50	67.25
V. ..	53.25	63.00	71.50	68.50	60.50

<i>1,000 Corn Weight (grams) dry</i>					
I. ..	43.5	46.1	46.5	45.9	45.5
II. ..	46.0	46.1	46.2	45.5	45.4
III. ..	42.7	41.7	40.9	44.9	43.6
IV. ..	43.7	43.7	45.3	43.8	42.9
V. ..	45.2	45.2	44.8	43.0	44.0

<i>Nitrogen per cent. on dry.</i>					
I. ..	1.42	1.56	1.51	1.50	1.64
II. ..	1.55	1.62	1.52	1.60	1.63
III. ..	1.54	1.52	1.56	1.48	1.56
IV. ..	1.47	1.47	1.53	1.46	1.57
V. ..	1.49	1.51	1.51	1.46	1.56

Mean Moisture percentage—16.1

SUMMARY OF RESULTS.

	O	S	M	C	N	Stand. Error.	Mean
Yield in bushels per acre	41.0	48.4	48.8	44.6	50.4	0.94	46.6
1,000 corn weight (grams) dry	44.2	44.6	44.7	44.6	44.3	0.014	44.5
Nitrogen per cent. on dry	1.49	1.54	1.53	1.50	1.59		1.53
Market valuation by Sub-Committee. Shillings per 448 lb.	43	43	43	43*	43		43
Samples bulked under Nos.	1	2	3	4	5		

* Slightly best.

Significant response in yield to all forms of Nitrogenous fertiliser, and in Nitrogen percentage to all except Cyanamide, to which the yield response is significantly lower than to the others. Nitrate of Soda gives a higher yield and significantly higher Nitrogen percentage than Sulphate or Muriate of Ammonia. No significant effect on 1,000 corn weight.
Not malted.

SECTION III. (TABLE 19). SEASON 1930.

SOUTH EASTERN AGRICULTURAL COLLEGE, WYE, KENT.

EFFECT OF CHLORIDES.

PLAN.

M./Pot.	Salt	O	Salt + M./Pot.
Salt	Salt + M./Pot.	M./Pot.	O
Salt + M./Pot.	O	Salt	M./Pot.
O	M. Pot.	Salt + M./Pot.	Salt

Latin Square. Plots $\frac{1}{16}$ th acre. Soil: Light chalk loam.

TREATMENTS: Salt at the rate of 88 lb. per acre and Muriate of Potash at the rate of 1 cwt. per acre.

Basal Manuring: Superphosphate at the rate of 4 cwt. per acre and Sulphate of Ammonia at the rate of 1 cwt. per acre.

Variety: Plumage-Archer. Barley sown: Mar. 4th. Harvested: Aug. 12th.

Previous Crop: Barley.

Row.	1,000 Corn Weight (Grams.) Dry.				Nitrogen per cent on Dry.			
	No salt or Potash.	Muri./Pot.	Salt.	M. Potash Salt.	No salt or Potash.	M./Pot.	Salt.	Salt and M./Pot.
I.	37.6	36.8	38.4	37.6	1.32	1.34	1.24	1.29
II.	36.8	38.0	37.1	37.2	1.34	1.28	1.34	1.28
III.	37.3	36.1	37.4	36.2	1.32	1.34	1.33	1.33
IV.	37.3	37.5	38.0	38.6	1.34	1.28	1.30	1.27

Mean Moisture percentage—15.4.

SUMMARY OF RESULTS.

Average Yield.	No Salt or Potash.	Muriate of Potash.	Salt.	Muriate of Potash & Salt.	Standard Error.	Mean.
Grain, bushels per acre	38.8	40.0	40.4	40.6	1.54	40.0
1,000 corn weight (grams)						
dry	37.2	37.1	37.7	37.4	0.20	37.4
Nitrogen per cent. on dry	1.33	1.31	1.30	1.30	0.009	1.31
Market valuation ..	49s.	49s.	49s.	49s.	—	49
Bulked sample numbers	81	82	83	84	—	—

No significant response in yield or 1,000 corn weight to Muriate of Potash or Salt. The lowering of the Nitrogen percentage by application of Salt is significant, the corresponding effect of Muriate of Potash fails to reach the 5% level of significance.

None malted.

SECTION III. (TABLE 20.) SEASON 1930.

G. H. NEVILLE, ESQ., WELLINGORE.

EFFECT OF NITROGENOUS FERTILISERS, and of Sulphate of Potash and Superphosphate.
Plan and Actual Weights in grams per sample.

K 172	KP 265	K 177	KP 214	KP 262½	O 213½	P 124	115K
P 159	O 159	O 159	P 129	K 196½	P 219½	O 184½	KP 124
P 128	K 182	K 236½	P 182½	K 116	P 146	KP 196½	P 199½
KP 188	O 179½	KP 183	O 156	KP 98½	O 134	K 209½	O 170½
O 107½	KP 134	KP 167½	P 196½	P 189½	O 144½	KP 195½	O 159½
P 119½	K 118	K 134	O 149	KP 191	K 207½	P 190	K 214½
P 191	KP 153½	K 103½	P 90	P 180	KP 225	K 198½	O 223½
O 155	K 170½	KP 97	O 80	K 153	O 172½	KP 212½	P 165½

Plan showing Nitrogenous Treatments
• applied to whole plots.

I. N C S O

II. S N O C

III. O S C N

IV. C O N S

SYSTEM OF REPLICATION : Latin Square.

AREA OF EACH WHOLE PLOT : ½th
acre

SOIL : Light Loam on Goltic limestone.

TREATMENTS :

O = No Nitrogen.

C = Cyanamide.

N = Nitrate of Soda

S = Sulphate of Ammonia

} at the rate
of 0.2 cwt
N per acre.Plots sub-divided to receive no Potash or Superphosphate (O), Sulphate of Potash (K) at the rate of 0.6 cwt. K_2O per acre, Superphosphate (P) at the rate of 0.4 cwt. P_2O_5 per acre, and Sulphate of Potash and Superphosphate (KP)

Plots harvested by sampling method.

Manures applied . March 10th.

Barley sown March 10th. Harvested .
August 22nd

Variety : Plumage-Archer.

Previous Crop : Barley.

		1,000 corn weight (grams) dry.				Nitrogen per cent. on dry.			
		O	S	C	N	O	S	C	N
I.	O	36.2	35.7	34.3	37.5	1.45	1.44	1.42	1.47
	K	35.0	35.0	35.3	37.7	1.44	1.36	1.38	1.53
	P	34.4	36.3	31.6	36.1	1.41	1.37	1.40	1.53
	PK	33.9	35.6	35.9	37.3	1.36	1.38	1.40	1.50
II.	O	37.1	34.2	32.7	37.9	1.46	1.40	1.47	1.47
	K	34.7	35.2	36.6	37.3	1.44	1.38	1.43	1.57
	P	33.9	32.9	34.9	33.9	1.41	1.41	1.42	1.53
	PK	33.1	34.9	36.9	36.1	1.43	1.39	1.40	1.51
III.	O	34.4	32.9	33.2	36.0	1.50	1.42	1.52	1.61
	K	36.4	34.4	33.6	36.1	1.46	1.36	1.38	1.64
	P	34.8	33.7	33.0	33.9	1.45	1.50	1.41	1.47
	PK	35.5	33.2	35.9	34.9	1.45	1.40	1.42	1.43
IV.	O	34.4	35.8	36.2	36.5	1.53	1.37	1.45	1.46
	K	34.8	37.5	36.7	34.7	1.45	1.42	1.38	1.48
	P	32.2	35.3	34.8	34.4	1.41	1.32	1.49	1.58
	PK	35.2	35.0	35.5	36.2	1.49	1.44	1.40	1.41

Mean Moisture percentage—13.5 (air dried).

SECTION III. (TABLE 20). SEASON 1930. WELLINGORE REPLICATED EXPERIMENT.

SUMMARY OF RESULTS.

	No Nitrogen.	S/Amm.	Cyana- mide.	Nit./Soda.	Standard Error.	Mean.
<i>Yield in Bushels per Acre.</i>						
No potash or super.	22.0	33.4	27.4	28.2	} 2.28	27.8
Sulphate of potash	19.8	31.0	33.4	33.8		29.6
Superphosphate	20.8	31.0	30.8	31.0		28.4
Potash and super.	19.8	36.2	32.8	37.8		31.6
Mean	20.6	32.8	31.2	32.8		29.4
<i>1,000 Corn Weight (grams) dry.</i>						
No potash or super.	35.5	34.6	34.1	37.0	} 0.71	35.3
Sulphate of potash	35.2	35.5	35.5	36.4		35.0
Superphosphate	33.8	34.5	33.6	34.6		34.1
Potash and super.	34.4	34.7	36.0	36.1		35.3
Mean	34.7	34.8	34.8	36.0	0.38	35.1
<i>Nitrogen per cent. on dry.</i>						
No potash or super.	1.48	1.41	1.46	1.50	} 0.029	1.46
Sulphate of potash	1.45	1.38	1.39	1.53		1.44
Superphosphate	1.41	1.40	1.43	1.53		1.44
Potash and super.	1.43	1.40	1.41	1.46		1.42
Mean	1.44	1.40	1.42	1.51	0.035	1.44

Significant increase in yield with all Nitrogenous fertilisers, but the differences between them are not significant. In presence of Nitrogenous dressing there is a significant increase in yield with Potash. The 1,000 corn weight is significantly raised by Nitrate of Soda but not by Sulphate of Ammonia or Cyanamide, and is significantly decreased by Superphosphate in the absence of Potash. Effects of fertilisers on Nitrogen percentage are not significant.

STOCK SAMPLES BULKED UNDER FOLLOWING SAMPLE NUMBERS.

	O	S	C	N
No K or P	21	25	33	29
K	22	26	34	30
P	23	27	35	31
KP	24	28	36	32

BULKED NITROGEN TREATMENTS MALTED.

Sample No.	Manurial Treatment.	Barley.				Malt.						Market valuation by sub-committee. Shillings.	
		Moisture, per cent.	1,000 corn weight (grams) dry.	Nitrogen per cent. on dry.	Making Loss, per cent. on dry.	Moisture, per cent.	Extract, per 336 lb. dry.	Colour.	Diastatic Power Lintner. ³	Cold Water Extract, per cent.	Permanently sol. Nitrogen, per cent. on dry.	Barley, 448 lb.	Malt, 336 lb.
21-24	No Nitrogen	13.7	34.7	1.45	9.6	3.0	99.7	3.5	46.5	22.8	0.53	29	48
25-28	S/Amm.	13.0	34.8	1.40	9.7	3.2	100.6	3.5	45.0	23.8	0.52	29	48
33-36	Cyanamide	13.6	34.8	1.42	9.8	3.3	99.7	3.3	45.5	23.2	0.50	29	48
29-32	Nitrate of Soda	13.2	36.0	1.51	9.5	3.0	99.7	3.3	48.0	23.7	0.56	29	48

SECTION III. (TABLE 21.) SEASON 1930.

MR. J. M. TEMPLETON, FARM INSTITUTE, SPARSHOLT, WINCHESTER.

EFFECT OF NITROGENOUS FERTILISERS and of Sulphate of potash and Superphosphate.

Plan and Actual Weights in Grams per Sample.

P 219	KP 186½	O 162½	P 132½	K 146	KP 161	K 152	KP 90½
O 174½	K 188½	K 165	KP 164	O 131	P 192	P 147	O 163
KP 209½	O 240½	O 171	KP 219	O 140	KP 209	KP 234½	P 159½
K 203	P 259	P 207	K 151	P 205	K 206	K 183	O 201
P 236½	O 203	P 160½	KP 191	K 177	P 172½	KP 185	P 133½
KP 257½	K 207½	O 160½	K 176½	KP 170½	O 163	K 173	O 156½
P 249½	KP 220½	K 215½	O 232½	P 150	KP 183	O 163½	P 126
O 259	K 230	KP 245	P 262	K 175	O 207½	KP 174½	K 102

Plan showing nitrogenous treatments
applied to whole plots.

I.	O	C	N	S
II.	C	S	O	N
III.	N	O	S	C
IV.	S	N	C	O

SYSTEM OF REPLICATION: Latin square.

AREA OF EACH WHOLE PLOT, 4½th
acre.

Soil: Thin stony loam on chalk.

Variety: Plumage-Archer.

TREATMENTS:

O = No Nitrogen
 C = Cyanamide
 N = Nitrate of Soda.
 S = Sulphate of Ammonia

} at the rate
 of 0.2 cwt.
 N per acre

Plots sub-divided to receive no Potash or Superphosphate (O), Sulphate of Potash (K), at the rate of 0.6 cwt. K_2O per acre, Superphosphate (P) at the rate of 0.4 cwt. P_2O_5 per acre, and Sulphate of Potash and Superphosphate (KP)

Plots harvested by sampling method.

Manures applied March 25th-26th

Barley sown April 15th Harvested August 12th-13th.

Previous Crop: Barley

SECTION III. (TABLE 21.)—SEASON 1930. SPARSHOLT REPLICATED EXPERIMENT.

		1,000 Corn Weights (Grams) Dry				Nitrogen per cent. on Dry.			
		O	S	C	N	O	S	C	N
I.	O	35.1	34.0	36.3	35.3	1.59	1.58	1.72	1.60
	K	36.7	34.3	34.0	33.7	1.66	1.59	1.70	1.64
	P	37.5	33.8	33.5	35.4	1.60	1.56	1.57	1.55
	PK	35.2	33.2	34.7	34.6	1.69	1.69	1.63	1.57
II.	O	34.6	33.8	36.4	35.7	1.63	1.60	1.64	1.68
	K	36.9	33.2	37.1	36.3	1.67	1.65	1.63	1.76
	P	34.0	35.3	37.0	35.2	1.85	1.67	1.59	1.65
	PK	35.6	34.8	35.8	37.4	1.60	1.56	1.62	1.72
III.	O	35.3	33.7	33.7	37.1	1.64	1.52	1.64	1.68
	K	35.0	34.3	33.8	35.6	1.53	1.55	1.65	1.63
	P	34.9	35.1	34.5	36.6	1.66	1.57	1.61	1.64
	PK	35.1	33.1	35.6	36.7	1.54	1.54	1.67	1.67
IV.	O	34.6	37.1	35.7	35.1	1.64	1.47	1.61	1.54
	K	32.5	36.1	35.2	35.7	1.60	1.60	1.55	1.51
	P	34.8	37.2	34.0	36.4	1.67	1.48	1.52	1.46
	PK	34.7	37.1	35.6	36.3	1.61	1.57	1.67	1.57

Mean Moisture percentage—13.0 (air dried)

SUMMARY OF RESULTS.

	No Nitrogen.	S/Amm.	Cyanamide.	Nitrate of Soda.	Standard Error.	Mean.
<i>Yield in Bushels per Acre.</i>						
No potash or superphosphate ..	23.8	28.2	28.6	28.6	1.84	27.2
Sulphate of potash	25.2	26.6	26.8	28.0		26.6
Superphosphate	26.6	29.0	25.2	31.8		28.2
Potash and superphosphate ..	28.4	26.2	27.6	33.6		29.0
Mean	26.0	27.6	27.0	30.4		27.8

<i>1,000 Corn Weight (Grams) Dry.</i>						
No potash or superphosphate ..	34.9	34.6	35.5	35.8	—	35.2
Sulphate of potash	35.3	34.5	35.0	35.3		35.0
Superphosphate	35.3	35.4	34.7	35.9		35.3
Potash and superphosphate ..	35.1	34.5	35.4	36.2		35.3
Mean	35.2	34.7	35.2	35.8	0.20	35.2

<i>Nitrogen per cent. on Dry.</i>						
No potash or superphosphate ..	1.62	1.54	1.65	1.62	—	1.61
Sulphate of potash	1.62	1.60	1.63	1.63		1.62
Superphosphate	1.70	1.57	1.57	1.58		1.60
Potash and superphosphate ..	1.61	1.59	1.65	1.63		1.62
Mean	1.64	1.57	1.62	1.62	0.020	1.61

Plots treated with Nitrate of Soda have given a significantly higher yield than all others; the response to Sulphate of Ammonia and Cyanamide is not significant. Apart from a lowering of the Nitrogen percentage by Sulphate of Ammonia there are no other significant effects, though an increased yield in presence of Superphosphate is indicated.

SECTION III. (TABLE 21.)—SEASON 1930. SPARSHOLT REPLICATED EXPERIMENT.

STOCK SAMPLES BULKED UNDER FOLLOWING SAMPLE NUMBERS.

	O	S	C	N
No K or P. ..	37	41	49	45
K.	38	42	50	46
P.	39	43	51	47
K. and P. ..	40	44	52	48

BULKED NITROGEN TREATMENTS MALTED.

Sample No.	Manurial Treatment.	Barley.					Malt.					Market valuation by Sub-Committee. Shillings.	
		Moisture per cent.	1,000 corn wt. grams. dry	Nitrogen per cent. on dry.	Malting loss per cent. on dry.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic power. Luthner.°	Cold water extract per cent.	Permanently sol. nitrogen % on dry.	Barley. 448 lb.	Malt, 336 lb.
37-40	No Nitrogen	13.2	35.2	1.64	8.6	2.9	100.3	3.4	48.0	21.2	0.54	28	46
41-44	S/Amm. ..	12.9	34.7	1.57	8.8	2.6	100.1	3.8	47.0	21.1	0.52	28	46
49-52	Cyanamide ..	12.8	35.2	1.62	9.4	2.9	99.9	3.2	47.5	20.8	0.52	28	46
45-48	Nitrate of Soda	12.9	35.7	1.62	9.0	3.1	99.5	3.0	48.0	20.5	0.52	28	46

SECTION III. (TABLE 22.) SEASON 1931.
ROTHAMSTED. FOSTERS FIELD. R.B. 1931.

UNDERSOWINGS FOR TEMPORARY LEY OF clover and rye grass.

I.	R.	—	—	O	—	C	CR	—
II.	—	O	R	—	CR	—	C	—
III.	—	CR	—	C	R	—	O	—
IV.	C	—	CR	—	O	—	—	R

NITROGENOUS FERTILISER. Sulphate of Ammonia.
SYSTEM OF REPLICATION : 4 × 4 Latin Square, with split plots.
AREA OF EACH SUB-PLOT : .05355 acre.
VARIETY : Plumage-Archer undersown with Italian Rye Grass (R) and Broad Red Clover (C).
TREATMENTS : Sulphate of Ammonia at the rate of 0.2 cwt. N per acre, applied to one out of each pair of sub-plots (indicated by the treatment symbol occurring on that half).
Manures applied : March 23rd.
Seed sown : Barley, March 23rd ; Rye Grass and Clover, April 23rd.
Harley Harvested : August 27th.
Previous crop : Temporary Ley.

Row.	Without Sulphate of Ammonia.				With Sulphate of Ammonia.			
	O	C	R	CR	O	C	R	CR

Actual Weights in lb.

I.	..	..	106.50	70.50	108.00	68.75	95.25	98.25	90.00	97.25
II.	..	..	112.25	82.00	100.50	76.25	112.50	99.50	120.50	61.75
III.	..	..	81.00	111.75	77.75	134.00	87.00	117.50	83.25	130.25
IV.	..	..	80.00	119.00	86.00	91.00	97.25	131.50	93.00	110.75

1,000 Corn Weight (Grams) Dry.

I.	..	..	41.4	41.9	40.7	40.3	41.4	41.5	40.3	39.7
II.	..	..	41.5	40.4	41.2	39.1	40.3	40.2	40.4	41.0
III.	..	..	40.1	39.9	39.5	42.0	40.4	40.9	41.4	41.4
IV.	..	..	39.8	41.4	40.6	40.9	41.4	41.0	39.5	40.8

Nitrogen per cent. on dry.

I.	..	..	1.65	1.73	1.71	1.66	1.72	1.68	1.68	1.69
II.	..	..	1.76	1.75	1.72	1.62	1.75	1.69	1.74	1.68
III.	..	..	1.74	1.70	1.69	1.77	1.61	1.71	1.65	1.71
IV.	..	..	1.72	1.71	1.68	1.79	1.72	1.82	1.66	1.64

Mean Moisture percentage—21.2.

SUMMARY OF RESULTS.

	Yield in bushels per acre.						1,000 corn weight (grams) dry.						Nitrogen per cent. on dry.					
	O	C	R	CR	Std. Error.	Mean.	O	C	R	CR	Std. Error.	Mean.	O	C	R	CR	Std. Error.	Mean.
Without S/Amm.	31.6	32.0	31.0	30.8	} 2.02	31.4	40.7	40.9	40.5	40.6	} 0.43	40.7	1.72	1.72	1.70	1.71	—	1.71
With S/Amm.	32.6	27.2	32.2	33.4		33.8	40.9	40.9	40.4	40.7		40.7	1.70	1.72	1.68	1.68		1.70
Mean ..	32.2	34.6	31.6	32.0	1.60		40.8	40.9	40.4	40.6	0.30	40.7	1.71	1.72	1.69	1.69	—	1.70

There are no significant effects.

	Without S/Amm.				With S/Amm.			
	O	C	R	CR	O	C	R	CR
Separate treatments bulked under sample numbers..	16	18	17	19	20	22	21	23
Market valuation by sub-committee, shillings, per 448 lb.	30	30	30	30	30	30	30	30

None malted.

SECTION III. (TABLE 23.)

SEASON 1931.

G. H. NEVILLE, Esq., WELLINGORE HALL, LINCS.—1931. (V.B.).

EFFECT OF NITROGENOUS FERTILIZERS AND OF SULPHATE OF POTASH AND SUPERPHOSPHATE.

PLANS AND ACTUAL WEIGHTS.

Grain (dry weights) lb.							
O	K	O	P	O	P	K	PK
19.4	17.9	17.8	17.7	18.0	15.7	19.0	17.6
P	PK	K	PK	PK	K	P	O
19.1	19.8	18.5	19.0	17.9	17.2	19.1	17.3
P	K	PK	O	P	K	K	P
21.5	21.5	23.4	20.3	19.3	17.9	18.9	19.2
O	PK	K	P	PK	O	PK	O
16.1	15.7	17.5	15.9	17.2	15.0	18.0	18.4
O	PK	P	O	P	K	P	K
16.6	15.5	14.5	15.8	15.0	14.7	16.8	13.2
P	K	K	PK	PK	O	O	PK
14.6	16.6	17.8	17.9	13.6	13.2	14.9	13.9
O	P	PK	K	K	PK	P	K
15.1	13.4	14.1	15.4	15.9	13.2	12.4	15.4
PK	K	O	P	P	O	O	PK
15.4	18.8	15.8	13.3	15.5	14.0	16.7	13.6

Plan showing Nitrogenous Treatments applied to whole plots.

SYSTEM OF REPLICATION: 4 × 4 Latin Square with plots sub-divided into 4.

AREA OF EACH WHOLE PLOT: $\frac{1}{16}$ th acre.

Soil: Light loam on Lincoln Heath
Variety: Plumage-Archer.

TREATMENTS:

O = No Nitrogen.
C = Cyanamide.
N = Nitrate of Soda.
S = Sulphate of Ammonia.

} at the rate
of 0.2 cwt.
N per acre.

I.	O	S	N	C
II.	S	O	C	N
III.	N	C	O	S
IV.	C	N	S	O

Plots sub-divided to receive no Potash or Superphosphate (O), Sulphate of Potash (K), at the rate of 0.6 cwt. K_2O per acre. Superphosphate (P) at the rate of 0.4 cwt P_2O_5 per acre, and Sulphate of Potash and Superphosphate (PK)

Plots harvested by sampling method.

Manures applied: March 27th.

Barley Sown: March 27th.

Barley harvested: September 2nd.

Previous Crop: Oats.

SECTION III. (TABLE 23.) SEASON 1931. WELLINGORE REPLICATED EXPERIMENT.

Row	1,000 corn weight (grams) dry				Nitrogen, per cent. on dry			
	O	S	N	C	O	S	N	C
<i>Effect of Nitrogenous Manures (The 4 sub-plots bulked).</i>								
I.	37.6	37.0	36.0	36.0	1.38	1.39	1.40	1.39
II.	36.0	37.5	36.2	36.3	1.35	1.33	1.35	1.33
III.	35.1	35.4	34.5	36.1	1.32	1.37	1.44	1.35
IV.	36.1	36.3	36.1	36.9	1.38	1.33	1.30	1.35

<i>Interaction of Nitrogenous and Mineral Manures.</i> (Bulked samples of each individual treatment.)								
No potash or superphosphate	36.8	36.4	35.1	36.5	1.39	1.40	1.38	1.38
Sulphate of Potash	36.5	36.4	36.3	36.5	1.33	1.32	1.40	1.40
Superphosphate	36.5	37.2	35.5	36.4	1.36	1.38	1.40	1.32
Potash and superphosphate	37.1	35.9	35.1	35.5	1.30	1.34	1.34	1.38

SUMMARY OF RESULTS.

	O	S	N	C	Standard Error	Mean
<i>Yield in bushels per acre.</i>						
No potash or superphosphate	62.2	56.0	61.4	56.4		59.0
Sulphate of potash	58.4	61.6	60.8	65.6		61.6
Superphosphate	55.8	63.8	56.0	59.2	2.86	58.8
Potash and superphosphate	62.8	55.2	58.4	60.8		59.4
Mean	59.8	58.2	59.2	60.6	2.50	59.6

<i>1,000 Corn weights (grams) dry.</i>						
O, K, P, and KP treatments bulked ..	36.2	36.5	35.7	36.3	0.43	36.2

<i>Nitrogen per cent. on dry.</i>						
O, P, K and KP treatments bulked ..	1.36	1.36	1.37	1.36	—	1.36

No significant effects.

	Market Valuation by Sub-Committee. Shillings per 448 lb.				Bulked samples kept under Nos.			
	O	S	N	C	O	S	N	C
					39, I-IV	40, I-IV	41, I-IV	42, I-IV
No potash or superphosphate ..	47	47	47	47	43	47	51	55
Sulphate of potash	47	47	47	47	44	48	52	56
Superphosphate	47	46	46	47	45	49	53	57
Potash and Superphosphate ..	47	47	47	47	46	50	54	58

None malted.

SECTION III. (TABLE 24.) SEASON 1931.

H. B. BESCOBY, Esq., SOUTH-EASTERN AGRICULTURAL COLLEGE, WYE, KENT.—1931. (Z.B.)

EFFECT OF NITROGENOUS FERTILIZERS AND OF SULPHATE OF POTASH AND SUPERPHOSPHATE.

PLAN AND ACTUAL WEIGHTS IN GRAMMES PER SAMPLE.

P	PK	P	PK	K	P	P	O
518	533	456	502	544	526	461	398
O	K	K	O	O	PK	K	PK
473	486	467	485	530	494	504	424
P	K	O	PK	K	P	P	K
474	417	528	484	420	407	424	463
O	PK	K	P	PK	O	PK	O
484	454	526	464	367	353	354	414
K	P	O	PK	O	K	O	PK
418	438	415	496	420	414	466	505
O	PK	P	K	P	PK	P	K
365	426	490	427	450	426	551	477
O	PK	PK	P	O	P	K	P
478	422	438	377	462	458	406	505
K	P	K	O	PK	K	O	PK
446	428	396	362	476	463	446	453

Plan showing Nitrogenous Treatments
applied to whole plotsSYSTEM OF REPLICATION : 4×4 LATIN
Square with plots sub-divided into 4.AREA OF EACH WHOLE PLOT : 1/50th acre
Soil : Silty Loam.

Variety : Plumage-Archer.

TREATMENTS :

O = No Nitrogen.

C = Cyanamide.

N = Nitrate of Soda.

S = Sulphate of Ammonia.

} at the rate
of 0.2 cwt.
N per acre

I.	N	C	S	O
II.	S	N	O	C
III.	O	S	C	N
IV.	C	O	N	S

Plots sub-divided to receive no Potash or
Superphosphate (O), Sulphate of
Potash (K) at the rate of 0.6 cwt. K_2O
per acre, Superphosphate (P) at the
rate of 0.4 cwt. P_2O_5 per acre, and
Sulphate of Potash and Superphos-
phate (PK.).

Plots harvested by sampling method.

Manures applied : March 26th.

Barley Sown : March 26th.

Harvested : August 16th

Previous Crop : Barley

SECTION III. (TABLE 24.) SEASON 1931. WYE REPLICATED EXPERIMENT.

Row	1,000 corn weight (grams) dry.				Nitrogen per cent. on dry.			
	O	S	N	C	O	S	N	C
<i>Effect of Nitrogenous Manures (The 4 sub-plots bulked).</i>								
I. ..	37.8	35.8	34.8	36.5	1.42	1.36	1.47	1.45
II. ..	37.3	35.9	36.3	36.7	1.46	1.46	1.47	1.39
III. ..	38.3	36.9	35.6	36.2	1.32	1.35	1.50	1.42
IV. ..	38.1	36.1	35.1	37.2	1.39	1.37	1.45	1.43

<i>Interaction of Nitrogenous and Mineral Manures.</i>								
(Bulked samples of each individual treatment.)								
No P or K	36.9	35.8	34.4	36.9	1.43	1.42	1.53	1.44
P ..	38.3	35.6	35.0	36.7	1.40	1.42	1.39	1.39
K ..	36.9	36.4	34.6	37.4	1.39	1.40	1.43	1.34
P and K	37.8	36.2	34.8	36.5	1.36	1.42	1.48	1.39

Mean Moisture percentage—14.7 (air dried)

SUMMARY OF RESULTS.

	O	S	N	C	Standard Error	Mean
<i>Yield in bushels per acre.</i>						
No potash or superphosphate	36.8	46.6	48.0	44.8	1.50	44.0
Sulphate of potash	43.2	44.6	48.6	44.6		45.2
Superphosphate	41.8	49.6	49.6	43.8		46.2
Potash and superphosphate	41.2	47.2	49.8	42.4		45.2
Mean	40.8	47.0	49.0	43.8	1.00	45.2
<i>1,000 corn weight (grams) dry.</i>						
O, K, P and KP treatments bulked ..	37.9	36.2	35.4	36.6	0.21	36.5
<i>Nitrogen, per cent. on dry.</i>						
O, K, P and KP treatments bulked ..	1.40	1.39	1.47	1.42	0.026	1.42

The response in yield to Nitrogen is definitely significant, the Sulphate of Ammonia and Nitrate of Soda being significantly superior to Cyanamide. Nitrogenous fertilisers significantly lower the 1000 corn weight, Nitrate of Soda having a significantly greater effect than the others. Both Potash and Super-phosphate lower the Nitrogen percentage by an amount which is just significant, but together they produce no further effect.

	Market Valuation by Sub-Committee. Shillings per 448 lb.				Bulked samples kept under Nos.			
	O	S	N	C	59, I-IV	60, I-IV	61, I-IV	62, I-IV
No potash or superphosphate ..	All 37s.				63	67	71	75
Sulphate of potash					64	68	72	76
Superphosphate					65	69	73	77
Potash and superphosphate ..					66	70	74	78

None malted.

SECTION IV. MISCELLANEOUS EXPERIMENTS. ROTHAMSTED AND OUTSIDE CENTRES.

Variety: *Pilgrimage Archer*.

TABLE 25.

Sample No.	Manurial Treatment.	Barley.				Malt.				Market Value by Sub-Committee.					
		Yield bushels per acre.	Moisture per cent.	1000 corn weight (grams) dry.	Nitrogen per cent. on dry.	Sol. in alcohol 80° F.	Diatase power in dry barley.	Making loss per cent. on dry.	Extract per 336 lb. dry.		Sinkers in water.	Colour.	Diatase power.	Cold water extract per cent.	Total Nitrogen per cent. on dry.	Permanently Soluble Barley
SEASON 1922															
ROTHAMSTED, LONG HOOS FIELD.															
118	Basal + 636 lb. acre Round Oak, slag and low grade high soluble	33.0	19.6	41.6	1.61	—	—	2.5	98.5	—	4.7	—	—	—	42
119	Basal (1 cwt. S/Amm). + 1 cwt. S/Pot. per acre	23.8	20.5	40.2	1.62	—	—	2.5	98.1	—	6.0	—	—	—	42
120	Basal + 436 lb. acre Park. gate slag; low-grade, high soluble	27.8	20.4	39.4	1.64	—	—	2.5	97.7	—	5.5	—	—	—	42
121	Basal (S/Amm. + 8 Pot.)	26.6	19.5	43.2	1.61	—	—	2.5	97.8	—	7.2	—	—	—	36
122	Basal (S/Amm. + 8 Pot.)	31.4	19.4	41.0	1.56	—	—	2.3	97.7	—	6.5	—	—	—	38
123	Nil	24.6	19.6	42.3	1.67	—	—	2.2	96.6	—	6.0	34.0	20.3	1.60	30
Average		27.9	19.8	41.3	1.62	—	—	2.4	97.7	—	6.0	—	—	—	38
ROTHAMSTED, LONG HOOS FIELD. TOP DRESSING.															
124	2 cwt. super + 1 cwt. S/Amm.	31.6	18.3	43.1	1.64	—	—	2.3	96.8	—	7.0	39.5	20.8	1.55	40
125	2 cwt. super + 2 cwt. S/Amm.	28.8	19.3	42.7	1.63	—	—	2.4	95.1	—	8.5	29.5	21.3	1.58	36
126	2 cwt. super. — no S/Amm.	21.7	19.1	44.4	1.62	—	—	37.1	96.2	—	8.0	31.0	20.2	1.58	40
127	2 cwt. super + 1 cwt. M/Amm.	25.2	19.7	47.5	1.69	—	—	37.0	96.9	—	6.0	31.0	20.4	1.69	40
Average		26.8	19.1	44.4	1.64	—	—	2.4	96.2	—	7.4	30.3	20.7	1.60	39
ROTHAMSTED, LITTLE HOOS FIELD.															
Nitrogen and potash with slag applied in —															
91	1919	—	17.5	46.7	1.57	—	—	2.6	40.6	26.7	5.8	96.4	—	—	45
88	1920	—	16.9	44.4	1.71	—	—	2.7	40.0	36.9	16.4	89.1	—	—	36
89	1921	—	17.5	44.5	1.58	—	—	2.7	40.0	31.5	12.0	92.9	—	—	40
90	1922	—	17.9	44.4	1.52	—	—	2.2	38.9	16.1	3.3	96.7	—	—	45
92	N and K only	—	18.1	46.2	1.59	—	—	2.3	40.0	9.5	2.2	97.7	—	—	45
Average		—	17.6	45.2	1.59	—	—	2.4	39.9	24.1	7.9	94.6	—	—	42
WOBBURN, GREAT HILL FIELD.															
73	Swedes fed off + phosphate	38.4*	18.3	38.7	1.64	—	—	10.5	91.6	2.2	—	—	—	—	32
74	Swedes fed off only	34.6*	20.0	39.6	1.65	—	—	10.0	93.8	2.1	—	—	—	—	32
Average		36.5*	19.2	39.2	1.64	—	—	10.2	92.7	2.2	—	—	—	—	32
* Measured bushels.															
SEASON 1923.															
ROTHAMSTED, LONG HOOS FIELD. Nitrogenous manure applied as top dressing.															
126	2 cwt. S/Amm. + 2 cwt. super.	27.6	18.1	44.2	1.81	—	—	7.1	99.7	—	—	—	—	—	68
130	Nil	19.8	17.6	43.1	1.79	—	—	8.0	99.1	—	—	—	—	—	66
Average		23.7	17.8	43.6	1.80	—	—	7.6	99.4	—	—	—	—	—	64

SECTION IV. (TABLE 25). MISCELLANEOUS EXPERIMENTS.

ROTHAMSTED, GREAT HARPENDEN FIELD.

Sample No.	Plot.	Manurial Treatment.	Barley.						Malt.					Market valuation by sub-committee. Shillings.	
			Moisture per cent.	1,000 corn weight (grms.) dry.	Nitrogen per cent. on dry.	Making loss per cent. on dry.	Extract calculated to 448 lb. raw.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic Power. Lintner.	Cold Water Extract per cent.	Barley 448 lb. Nov., 1924.	Malt. 336 lb. Dec., 1924.	
SEASON 1924.															
119	Silicate set—H. 11 & 35	Basal (1 cwt. Sulphate of Potash and 107 lb. Sulphate of Ammonia)	17.5	40.3	1.55	8.9	98.6	2.0	98.4	6.0	27.0	22.3	65	85	
120	H. 4 & 28	Basal with Phosphate	17.3	38.7	1.50	9.0	99.1	2.0	98.8	7.0	23.0	22.0	65	82	
121	H. 12 & 29	Basal with Silicate	17.6	40.0	1.54	9.0	97.9	1.9	97.9	6.5	26.0	22.1	65	85	
122	H. 10 & 30	Basal with Phosphate and Silicate	17.2	40.3	1.51	9.4	98.9	2.3	98.8	7.0	27.5	21.4	65	90	
	Average		17.4	39.8	1.52	9.1	98.6	2.0	98.5	6.6	25.9	22.0	65	86	
SEASON 1925.															
124	Nitrogen set—N.4 & 13	Basal with 1 cwt. acre Sulphate of Ammonia	17.3	40.9	1.50	9.1	98.9	2.2	98.7	5.5	24.5	20.0	66	96	
125	N.5 & 12	Basal with 2 cwt. acre Sulphate of Ammonia	16.5	40.7	1.41	8.7	101.0	2.0	99.2	5.5	22.0	20.3	66	95	
126	N.6 & 11	Basal with 1 cwt. acre Muriate of Ammonia	17.0	41.3	1.51	9.6	98.9	2.2	98.8	6.5	24.5	21.2	66	95	
127	N.7 & 10	Basal with 2 cwt. acre Muriate of Ammonia	17.0	42.0	1.51	8.6	98.9	2.0	97.7	6.5	23.5	20.6	66	95	
128	N.3 & 14	Basal (2 cwt. Super. and 1 cwt. Sulphate of Potash)	16.9	42.1	1.57	8.9	97.1	2.1	96.3	5.5	28.0	21.3	63	90	
130	N.8 & 1	Basal with Urea	16.7	40.0	1.50	8.7	99.8	2.2	98.5	5.5	27.5	20.0	66	96	
	Average		16.9	41.7	1.50	8.9	99.1	2.1	98.2	5.8	25.0	20.6	66	95	

SEASON 1925.
PHOSPHATE EXPERIMENTS.

Sample No.	Manurial Treatment.	Barley					Malt.					Market valuation by Sub-Committee. Shillings.	
		Moisture per cent.	1,000 corn weight (grms.) dry.	Nitrogen per cent. on dry.	Making loss per cent. on dry.	Extract calculated to 448 lb. raw.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic power. Lintner.	Cold Water extract per cent.	Barley 448 lb. Nov., 1925.	Malt 336 lb. Dec. 1925.
CHESHIRE AGRICULTURAL COLLEGE, REES HEATH, NANTWICH.													
191	N+K ..	19.2	38.7	1.60	10.1	93.8	2.5	96.9	7.5	27.0	21.5	40	69
192	P+K ..	19.4	39.0	1.59	10.0	93.4	2.4	97.1	6.3	31.0	21.1	40	69
193	N+P+K ..	19.4	39.1	1.68	10.2	93.7	2.3	97.2	7.5	32.0	23.6	40	60
194	K+only ..	19.5	39.9	1.57	9.9	94.5	2.7	97.7	6.5	32.0	22.1	40	60

ROTHAMSTED EXPERIMENTAL STATION, SAWYER S FIELD.

195	N+K ..	17.8	41.9	1.80	12.9	91.1	2.5	95.5	16.5	12.5	28.7	53	N/A		
196	P+K ..	17.8	43.4	1.74	12.7	91.0	2.6	95.3	14.0	13.5	28.1	53	N/A		
197	N+P+K ..	18.2	41.6	1.70	14.0	89.4	2.4	95.7	16.8	12.5	28.7	53	N/A		
198	K only ..	18.3	42.9	1.73	13.7	90.1	2.4	95.9	16.5	14.0	28.5	53	N/A		

SECTION IV. (TABLE 26). MISCELLANEOUS EXPERIMENTS.
LARGE PLOTS, ENGLISH 6-ROWED BARLEY. AUTUMN SOWN.
Dr. E. S. BEAVEN'S F.112.

Sample No.	Grown at	Barley.							Malt.							Market valuation by sub-committee Shillings.	
		Yield in bushels per acre.	Moisture per cent.	1000 corn weight (grams) dry.	Nitrogen per cent. on dry.	Making loss per cent. on dry.	Extract calculated to 448 lb. raw.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic power.	Lintner.	Cold water Extract per cent.	Permanently soluble N per cent. on dry.	Barley per 448 lb.	Malt per 336 lb.	
SEASON 1928.																	
GROWN BY MR. J. M. STRATTON AT PERTWOOD, WILTS., AND MR. R. STRATTON, AT KINGSTON DEVERILL, WILTS. Heavy Soils, overlying chalk.																	
SWEATED AND SCREENED BARLEYS, MALTED IN STOCKING BY H. M. LANCASTER, BULKED AND MALTED COMMERCIALY BY MESSRS. J. D. TAYLOR, BATH.																	
400 a	Pertwood	34	14.4	32.4	1.29	9.9	-	3.4	95.2	5.0	33.0	20.4	0.46	38	61		
400 b	Kingston Deverill	40	12.0	35.5	1.33	8.7	-	3.3	96.2	4.2	42.5	22.5	0.43	38	63		
400 a/b	(Bulk Malt)							1.9	96.2	12.5	24.0	22.7	0.44	—	—		
SEASON 1929.																	
GROWN BY MR. G. F. GAUNTLETT, AT NORTH BAVANT, WILTS., AND MR. MARSHMAN (? WILTS). Chalk soil. SCREENED AND SWEATED BARLEYS, MALTED IN BULK BY MESSRS. J. GROVES & SONS, WEYMOUTH.																	
91	N. Bavant	60	12.4	35.8	1.37			4.7	93.5	6.0	23.0	16.1	0.39	—	—		
92		—	13.9	37.6	1.30			4.4	95.9	3.2	35.0	16.6	0.40	—	—		

TABLE 27.
SEASON 1930
WOBURN EXPERIMENTAL STATION. STACKYARD FIELD.
SIX COURSE ROTATION (ROTATION II).

Plots $\frac{1}{4}$ th acre TREATMENTS	Plot Plan and yield of Grain in Bushels per acre															
	1K	2K	0N	1N	2P											
N—4, 3, 2, 1 and 0 units of N, each with 2 units P_2O_5 and 2 units K_2O																
K—4, 3, 2, 1 and 0 units of K_2O , each with 2 units N and 2 units P_2O_5	41.4	39.2	27.2	37.8	44.2											
P—4, 3, 2, 1 and 0 units of P_2O_5 , each with 2 units N and 2 units K																
1 unit of N—0.15 cwt. N per acre as Sulphate of Ammonia.	3K	0K	4N	1P	0P											
1 unit of K—0.25 cwt. K_2O per acre as Muriate of Potash.	42.2	38.6	46.0	44.2	44.0											
1 unit of P—0.15 cwt. P_2O_5 per acre as Superphosphate.																
Manures applied Mar. 22nd.	4K	2N	3N	3P	4P											
Seed sown Mar. 28th.																
Harvested Aug. 13th-14th by large scale method.	40.8	36.4	41.4	38.8	41.0											
Variety : Plumage-Archer.																
Sample No.	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Manurial Treatment.	0N	1N	2N	3N	4N	0K	1K	2K	3K	4K	0P	1P	2P	3P	4P	
1000 Corn weight (grams) dry	33.9	33.1	34.7	33.6	33.7	33.8	32.9	35.7	35.0	36.2	35.4	34.4	35.9	33.4	35.0	
Nitrogen per cent. on dry	1.37	1.34	1.50	1.56	1.71	1.47	1.55	1.45	1.51	1.57	1.43	1.47	1.43	1.51	1.42	
Market Valuation by Sub-Committee, shillings per 448 lb.	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	

Mean Moisture percentage at analysis—13.7.

SECTION IV. (TABLE 27.) SEASON 1930.

Woburn, (Rotation II), 1930. (contd.)

Two mixtures malted.

	Barley.					Malt.						Market Valuation by Sub-committee.	
	Moisture per cent.	1000 corn weight (grams) dry.	Nitrogen per cent. on dry.	Maling loss per cent. on dry.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic power. Lintner°.	Cold water Extract per cent.	Perm. sol. nitrogen per cent. on dry.	Barley, shillings per 336 lb.	Malt.	
Low Nitrogen, 6, 7, 16, 17, 18, 20	14.1	35.0	1.41	8.1	3.3	99.0	3.0	38.5	17.1	0.47	24	Malts not valued; high Nitrogen slightly best.	
High Nitrogen, 9, 10, 12, 14, 15, 19	12.2	34.1	1.57	0.5	3.3	97.8	3.9	43.5	17.5	0.52	24		

TABLE 28.
SEASON 1931.
ROTHAMSTED EXPERIMENTAL STATION. LONG HOOS FIELD
SIX COURSE ROTATION (ROTATION II).

Plot plan and yield of grain in Bus. per acre.

Plots and Treatments as in corresponding experiment at Woburn (see above).

Manures applied : Feb. 27th.

Seed sown : March 6th.

Harvested : Aug. 29th, by sampling method

Variety : Plumage-Archer.

2K	0K	0P	2P	3N
44.4	38.4	38.4	45.2	40.8
3K	1K	4N	4K	0N
40.0	50.4	42.8	41.8	26.4
4P	3P	1P	2N	1N
38.8	39.2	37.8	41.2	37.8

Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Manurial Treatment.	0N	1N	2N	3N	4N	0K	1K	2K	3K	4K	0P	1P	2P	3P	4P
1000 corn wt. (grams) dry	43.6	45.9	45.4	45.1	43.6	50.0	44.9	45.1	45.5	45.8	43.8	44.9	46.1	44.2	44.2
Nitrogen per cent. on dry	1.67	1.64	1.64	1.52	1.80	1.78	1.69	1.75	1.65	1.60	1.64	1.70	1.65	1.68	1.61
Market valuation by Sub-com- mittee. Shillings per 448 lb.	28	28	28	28	28	27	30	27	28	27	28	27	30	30	30

Mean Moisture percentage (air dry samples)—13.4.

Not Malted.

SECTION V. (TABLE 29.) HOOS PERMANENT PLOTS.

SEASON 1923.														
Sample No.	Plot.	Barley.						Malt.					Market Valuation by Sub-Committee. Shillings.	
		Yield per acre.	Moisture per cent.	1,000 corn weight (grams) dry.	Nitrogen per cent. on dry.	M/L as % of Dry Matter.	Extract per 448 lb Raw Barley.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic power. Lintner.	Cold Water Extract per cent.	Barley per 448 lb. Jan., 1924.	Malt per 336 lb. Jan., 1924.
93	O1	10.1	19.10	40.2	1.734	5.2	96.7	1.08	94.4	7.0	41.5	21.7	43.0	55
94	O2	19.6	17.20	40.7	1.543	7.0	101.8	1.22	98.5	3.8	40.5	20.2	54.0	77
95	O3	12.0	18.58	39.5	1.708	8.0	98.1	1.26	98.2	7.3	40.5	22.0	43.0	60
96	O4	16.0	18.02	41.0	1.587	7.3	102.2	1.10	100.2	5.0	41.5	21.0	43.0	75
97	A1	13.0	16.84	41.7	2.072	7.7	98.2	1.20	95.9	4.0	45.0	20.7	49.0	55
98	A2	22.6	16.14	40.7	1.770		Not malted							
99	A3	16.0	16.46	43.3	1.913	8.2	97.7	1.10	95.5	3.7	46.0	20.9	48.0	55
100	A4	33.0	15.70	41.5	1.874	7.0	105.3	1.20	100.8	3.7	43.0	20.7	56.0	75
104	AA4	31.0	16.20	41.8	1.688	6.9	104.0	1.34	99.9	4.5	38.5	20.6	50.0	75
105	AAS1	21.0	16.42	44.2	1.934	7.7	99.0	1.22	96.1	5.2	41.5	21.9	41.6	60
106	AAS2	35.0	16.52	42.7	1.705	7.5	103.4	1.16	100.2	5.0	40.0	22.3	50.0	70
107	AAS3	22.6	17.02	45.0	1.810	6.9	100.5	1.10	97.5	5.5	40.0	21.5	41.6	60
108	AAS4	36.0	16.54	42.8	1.577	7.8	102.3	1.16	99.8	4.8	37.0	21.8	56.0	70
109	7-1	17.3	17.00	42.6	1.663	7.2	102.5	1.62	99.7	4.0	34.0	21.2	46.0	70
110	7-2	30.6	16.14	44.9	1.899	7.5	102.0	1.76	98.6	4.0	38.0	19.5	50.0	70
111	6-1 & 2	10.0	16.94	41.1	1.711	8.0	100.4	1.74	98.5	4.5	36.0	21.6	44.0	60
116	C4	34.5	16.80	43.6	1.697	6.8	104.1	1.14	100.6	3.7	40.0	20.5	54.0	75
117	N2	22.7	16.94	43.5	1.831	7.8	99.8	1.40	97.8	4.8	38.0	21.1	41.0	60

SEASON 1924.													Nov. 1924	Dec., 1924
109	7-1	1.8	18.06	34.4	1.332	10.5	94.9	2.68	97.1	12.5	20.0	22.5	Black	Not valued
110	7-2	25.3	19.78	41.2	1.541	10.1	93.3	2.24	97.4	12.5	25.0	22.1	60	
112	6-2	1.6	18.42	34.8	1.324	9.8	96.7	2.20	98.5	13.0	19.5	22.8	Black	

SECTION V. (TABLE 29.) HOOS PERMANENT PLOTS.

Sample No.	Plot	Barley.					Malt.					Market valuation by Sub-Committee. Shillings.	
		Moisture per cent.	1,000 corn weight (grams) dry.	Nitrogen per cent. on dry.	Making loss per cent. on dry.	Extract calculated to 448 lb. raw.	Moisture per cent.	Extract per 336 lb. dry.	Colour	Diastatic power. Lintner°	Cold water Extract per cent.	Barley per 448 lb. at	Malt per 336 lb. at
SEASON 1925.												Nov., 1925.	Dec., 1925.
93	O 1	18.14	28.0	1.438	13.2	89.5	2.34	94.6	12.0	15.0	27.7	49	Nil
94	O 2	17.90	32.5	1.491	15.6	86.2	2.44	93.7	20.0	10.0	28.6	50	
95	O 3	17.74	28.0	1.378	14.0	90.1	2.30	95.6	14.5	13.0	27.1	47	
96	O 4	17.42	31.1	1.472	15.9	85.2	2.38	93.3	20.0	10.5	27.7	48	
97	A 1	19.80	28.5	1.765	15.5	81.2	2.70	90.2	20.0	13.5	27.9	47	
98	A 2	18.28	34.4	1.866	15.3	83.0	2.48	90.0	28.0	10.5	28.2	51	
99	A 3	17.72	32.0	1.817	15.8	83.2	2.48	90.0	27.0	12.5	28.0	47	
100	A 4	19.70	35.9	1.623	14.8	83.0	2.48	91.1	20.0	13.0	26.0	51	
101	AA 1	18.42	30.4	1.771				not malted.				47	
102	AA 2	17.94	38.0	1.598				"	"			56	
103	AA 3	18.28	30.9	1.711				"	"			47	
104	AA 4	17.90	36.4	1.561	18.1	83.7	2.48	93.4	26.0	10.0	27.5	56	
105	AAS 1	19.36	32.6	1.689	13.3	87.8	2.32	94.2	18.5	11.5	26.4	54	59
106	AAS 2	18.76	38.0	1.620	13.3	87.7	2.20	93.7	22.5	10.0	24.3	54	Nil
107	AAS 3	17.98	32.8	1.627	14.6	87.3	2.24	93.6	22.5	10.5	24.2	54	
108	AAS 4	18.14	36.9	1.556	14.1	88.8	2.62	94.5	19.0	11.5	25.0	54	
109	7-1	17.84	31.2	1.476				not malted.					
110	7-2	17.78	38.3	1.823	18.0	82.6	3.14	91.9	33.0	11.5	24.6	54	
112	6-1	17.27	30.5	1.500	16.1	88.6	2.68	95.5	18.0	13.0	24.7	54	
113	C-1	18.40	35.2	1.708				not malted.					
114	C 2	18.32	37.1	1.612				"	"				
115	C 3	18.76	35.7	1.567				"	"				
116	C 4	18.10	37.3	1.601	13.7	87.2	2.82	93.0	16.5	11.5	22.3	54	
117	N 2	18.08	34.6	1.629				not malted.					
SEASON 1926.												Nov., 1926	Dec., 1926
93	O 1	18.3	34.7	1.609	11.2	94.4	3.16	97.8	5.7	47.0	23.4	37	53
94	O 2	17.7	37.3	1.541	10.3	98.0	3.00	99.6	5.7	46.5	23.7	45	56 D
95	O 3	17.7	33.4	1.597	11.6	94.4	2.92	97.3	6.7	47.0	25.0	37	51 D
96	O 4	17.8	36.8	1.630	10.7	96.6	3.02	98.5	6.7	52.0	24.3	38	52
97	A 1	17.6	35.9	1.724	11.0	94.8	3.28	97.1	5.3	59.0	23.7	38	52
98	A 2	17.8	34.7	1.646	10.1	97.1	2.92	98.5	5.7	49.0	23.2	39	52
99	A 3	18.0	34.4	1.810	11.7	92.2	2.66	95.7	7.5	59.5	24.4	37	51
100	A 4	18.7	34.7	1.547	10.0	97.6	2.96	99.1	5.2	50.5	23.7	39	53
101	AA 1	17.4	37.3	1.818	11.0	96.6	2.96	96.6	5.7	60.5	23.2	37	51
102	AA 2	17.7	34.4	1.610	10.2	97.2	3.00	98.7	5.5	53.0	24.2	39	53
103	AA 3	17.9	34.2	1.789	12.4	91.2	2.98	95.5	8.2	56.0	24.6	37	51
104	AA 4	18.8	35.7	1.608	10.7	95.5	2.64	98.9	6.2	50.5	22.6	39	53
109	7-1	17.9	36.1	1.595	11.8	95.0	3.18	98.5	6.5	49.0	23.0	39	54 D
110	7-2	17.8	38.0	1.761	10.5	95.2	3.26	97.2	5.5	59.5	22.6	40	54
112	6-1	18.4	37.0	1.751	10.6	94.3	3.12	97.6	5.7	50.5	23.7	38	53

SECTION IV. (TABLE 29.)

ROTHAMSTED. PERMANENT BARLEY PLOTS, GREAT HOOS FIELD (*contd.*)

Variety : *Spratt-Archer*. (37/6.)

Sample No.	Plot.	Barley.						Malt.					Market Valuation by Sub-Committee. Shillings.	
		Moisture, per cent.	1,000 corn weight (grams) dry.	Nitrogen, per cent. on dry.	Making Loss, per cent. on dry.	Extract, calculated to 448 lb. raw.	Moisture, per cent.	Extract, per 336 lb. dry.	Colour.	Diastatic power. Lintner.	Cold Water Extract.	Barley, per 448 lb.	Malt, per 336 lb.	
SEASON 1927.														
93	1.0	19.3	30.8	1.32	8.6	99.7	3.6	101.3	4.7	36.5	22.2	47	72	
94	2.0	21.2	32.3	1.36	8.5	95.3	3.7	99.2	4.6	32.5	18.3	37	Gr.	
95	3.0	19.1	29.3	1.25	9.6	98.3	3.4	100.8	5.0	36.0	23.7	45	72	
96	4.0	19.7	32.2	1.42	9.2	98.8	3.3	100.4	4.3	30.0	21.8	45	72	
97	5.0	21.3	34.2	1.50	8.8	98.4	3.7	99.1	5.3	36.0	18.7	38	Gr.	
98	1.A	19.3	33.1	1.30	8.6	100.0	3.4	101.7	4.0	39.5	22.4	47	72	
99	2.A	21.4	30.6	1.37	7.7	97.0	3.7	100.3	4.0	43.0	21.2	43	72	
100	3.A	19.0	34.1	1.26	12.8	94.0	3.6	99.8	5.0	32.5	18.5	38	Gr.	
101	4.A	18.3	38.4	1.43	11.9	98.3	3.7	102.2	4.5	35.0	20.9	45	70	
100 A	5.A	21.1	36.7	1.51	10.1	95.6	3.4	101.0	5.5	36.0	18.8	43	Gr.	
101	1.AA	18.6	34.1	1.39	8.9	99.8	3.6	100.9	4.0	39.5	22.0	47	72	
102	2.AA	20.9	33.4	1.35	8.5	98.4	3.6	101.9	4.3	40.5	20.7	46	72	
103	3.AA	18.9	33.4	1.32	9.3	98.8	3.6	100.7	4.2	42.0	22.4	47	72	
104	4.AA	21.3	37.0	1.34	8.4	98.7	3.6	102.7	4.5	37.0	20.7	45	70	
109	7.1	20.8	34.5	1.35	8.5	96.2	3.4	99.6	4.2	43.5	21.4	39	Gr.	
110	7.2	20.8	41.0	1.75	9.2	95.0	3.2	99.1	4.0	37.5	20.6	39	Gr.	

SEASON 1928.

No Samples.

(TABLE 30.) HOOS PERMANENT BARLEY PLOTS.

ALTERNATE STRIPS SOWN WITH PLUMAGE-ARCHER AND SPRATT-ARCHER.

Sample No.	Plot.	Variety.	Moisture, per cent.	Nitrogen per cent. on dry.	Market valuation by sub-committee. Shillings per 448 lb.
SEASON 1929.					
83	1.0	Pl. Arch.	—	—	30
87	1.0	Sp. Arch.	14.0	1.77	30
84	4.0	Pl. Arch.	—	—	30
88	4.0	Sp. Arch.	—	—	30
85	4.A	Pl. Arch.	—	—	30
89	4.A	Sp. Arch.	14.2	1.74	30
86	7.2	Pl. Arch.	—	—	30
90	7.2	Sp. Arch.	—	—	30

SECTION IV. (TABLE 30.) HOOS PERMANENT BARLEY PLOTS.

SEASON 1930.

Sown longitudinally with a row spacing of 18 inches. The two varieties were sown by the half-drill strip method, and to equalise the area, certain rows at the sides of each plot were not included in the weighed produce.

Sample Nos.	Plot.	Manuring (Amounts stated are per acre).	Total Grain per acre.		76 Years' average 1852-1928. Dressed Grain per acre.	1,000 corn wt (grams) dry.		Nitrogen per cent. on dry.		Grading by sub-committee.
			Plumage-Archer bush.†	Spratt-Archer, bush.†		Plumage-Archer.	Spratt-Archer.	Plumage-Archer.	Spratt-Archer.	
53	1 O	Unmanured	1.4	1.4	13.4	35	30	2.19	2.14	4
54	2 O	Superphosphate only (3½ cwt.) ..	19.6	18.2	19.0	48	44	1.71	1.63	1
55	3 O	Alkali Salts only (200 lb. Sulphate of Potash; 100 lb. Sulphate of Soda; 100 lb. Sulphate of Magnesia)	7.2	6.0	14.3	46	40	1.92	1.88	4
56	4 O	Complete Minerals; as 3 O with Superphosphate (3½ cwt.) ..	14.4	19.0	19.0	47	45	1.78	1.74	4
57	5 O	Potash (200 lb.) and Superphosphate (3½ cwt.)	16.8	16.6	15.5	47	42	1.75	1.70	2 & 3 resp.
58	1 A	Ammonium Salts only (206 lb. Sulphate of Ammonia) ..	5.8	8.2	23.7	43	37	2.38	2.30	4
59	2 A	Superphosphate and Amm. Salts ..	36.0	37.8	35.8	47	40	1.86	1.85	2
60	3 A	Alkali Salts and Amm. Salts ..	15.6	10.6	25.8	45	40	2.23	2.26	3
61	4 A	Complete Minerals and Amm. Salts ..	29.6	35.4	39.3	46	43	1.70	1.69	2
62	5 A	Potash, Super. and Amm. Salts ..	26.6	24.2	33.8	47	43	1.66	1.72	2
63	1 AA	Nitrate of Soda only (275 lb.) ..	9.4	9.6	24.3*	44	36	2.34	2.33	4
64	2 AA	Superphosphate and Nitrate of Soda ..	36.2	38.0	38.8*	45	42	1.76	1.66	2
65	3 AA	Alkali Salts and Nitrate of Soda ..	16.0	16.0	24.5*	45	44	2.16	2.10	3
66	4 AA	Complete Minerals and Nitrate of Soda	34.0	34.8	37.7*	44	41	1.61	1.66	1
67	1 AAS	As Plot 1 AA and Silicate of Soda (400 lb.)	13.8	22.0	30.2*	49	42	2.25	2.20	3
68	2 AAS	As Plot 2 AA and Silicate of Soda (400 lb.)	41.0	42.8	39.7*	45	42	1.70	1.72	3
69	3 AAS	As Plot 3 AA and Silicate of Soda (400 lb.)	25.6	27.0	31.2*	49	44	2.06	2.04	4
70	4 AAS	As Plot 4 AA and Silicate of Soda (400 lb.)	38.4	42.0	39.9*	47	44	1.75	1.74	4
71	1 C	Rape Cake only (1,000 lb.) ..	23.8	25.0	35.5	47	42	1.70	1.69	2
72	2 C	Superphosphate and Rape Cake ..	36.0	36.2	38.1	44	42	1.61	1.61	2
73	3 C	Alkali Salts and Rape Cake ..	29.2	32.8	33.7	46	42	1.66	1.62	2
74	4 C	Complete Minerals and Rape Cake ..	33.2	35.6	37.5	48	42	1.72	1.74	4
75	7-1	Unmanured (after dung (14 tons) for 20 years (1852-71) ..	15.8	19.6	22.5†	47	44	1.66	1.68	4
76	7-2	Farmyard Manure (14 tons) ..	30.6	32.6	44.6	49	47	1.88	1.93	4
77	6-1	Unmanured since 1852 ..	6.6	3.8	14.7	46	42	1.92	1.91	4
78	6-2	Ashes from Laboratory furnace ..	9.2	11.4	15.7	46	42	1.82	1.93	4
79	1 N	Nitrate of Soda only (275 lb.) ..	8.4	6.8	28.7§	42	35	2.04	1.98	4
80	2 N	Nitrate of Soda only (275 lb.) ..	27.0	20.6	31.7§§	47	43	1.94	1.79	4

|| Measured bushels. 1912, all plots were fallowed.

† Weighed bushels (56 lb.).

* 60 years, 1868-1928. † 56 years, 1872-1928. § 75 years, 1858-1928. §§ 69 years, 1859-1928.

NOTE ON 1930 GRADING.—Apart from No. 57, only minor irregular differences noted between the two varieties. Nos. 53, 56 and 70 noted as extremely bad barleys. Grades 1, 2, 3, 4 correspond to valuations of 45/-, 38/-, and 26/- per 448 lbs., and grading barley respectively.

SECTION IV. (TABLE 30.) HOOS PERMANENT BARLEY PLOTS.

SEASON 1931.

ALTERNATE STRIPS SOWN WITH PLUMAGE-ARCHER AND SPRATT-ARCHER.

Sample No.	Plot.	Variety.	1,000 corn weight (grams) dry.	Nitrogen, per cent. on dry.
170 P	1·0	Pl. Arch.	43	1·80
170 S	1·0	Sp. Arch.	40	1·73
171 P	2·0	Pl. Arch.	46	1·60
171 S	2·0	Sp. Arch.	43	1·59
172 P	3·0	Pl. Arch.	42	1·65
172 S	3·0	Sp. Arch.	—	1·61
173 P	4·0	Pl. Arch.	—	—
173 S	4·0	Sp. Arch.	44	1·74
174 P	5·0	Pl. Arch.	46	1·81
174 S	5·0	Sp. Arch.	44	1·68
175 P	5·A	Pl. Arch.	—	—
175 S	5·A	Sp. Arch.	44	1·79
176 P	6·1	Pl. Arch.	—	1·62
176 S	6·1	Sp. Arch.	—	1·75
177 P	6·2	Pl. Arch.	—	1·55
177 S	6·2	Sp. Arch.	—	1·59
178 P	7·1	Pl. Arch.	46	1·74
178 S	7·1	Sp. Arch.	43	1·73
179 P	1·N	Pl. Arch.	—	1·91
179 S	1·N	Sp. Arch.	—	1·81
180 P	2·N	Pl. Arch.	—	1·98
180 S	2·N	Sp. Arch.	—	1·89

SECTION VI.

VARIETY TRIALS, NATIONAL INSTITUTE OF AGRICULTURAL BOTANY AND ASSOCIATED CENTRES.

TABLE 31. SEASON 1922.

Sample No.	Variety.	Barley.					Malt.								
		Moisture per cent.	1,000 corn weight (grams) dry.	Nitrogen per cent. on dry.	M/L as % of Dry Matter.	Extract per 448 lb. Raw Barley.	Moisture per cent.	Extract on dry malt.	Colour.	Diastatic Power. Lintner. °	Cold water extract per cent.	Nitrogen on dry malt. per cent.	pH of hot mash.	Class.	
N.I.A.B., CAMBRIDGE.															
131/6	Beaven's 1920 ..	13.02	40.9	1.69	11.6	93.5	1.84	96.0	6.5	41.5	18.9	1.635	5.6	3	
132/7	Webb's B. ...	12.43	38.5	1.85	10.9	93.8	1.98	96.4	5.7	43.0	19.5	1.801	5.6	3	
131/8	Golden Pheasant ..	12.64	41.1	1.94	11.9	92.8	2.00	96.3	7.0	40.0	20.1	1.883	5.6	3	
134/9	Cambridge 59/120..	13.15	—	1.94	—	—	—	—	—	—	—	—	—	—	
135	Garton, 1917 ..	12.12	38.4	1.90	11.6	91.4	1.92	93.9	6.0	41.5	19.3	1.859	5.6	3	
140	Archer ..	12.07	36.0	1.82	11.7	91.5	1.80	93.8	6.5	41.5	20.0	1.757	5.6	3	
WALLIS GRANGE, YORKS															
151	Beaven's 1920 ..	10.59	41.5	1.42	10.4	97.0	1.90	98.2	5.0	26.0	18.8	1.296	5.6	—	
152	Webb's B. ...	10.46	—	1.43	—	—	—	—	—	—	—	—	—	—	
153	Golden Pheasant ..	10.50	42.6	1.67	11.0	95.0	1.86	96.9	5.0	28.5	19.7	1.550	5.6	—	
154	Cambridge 59/120..	10.91	—	1.65	—	—	—	—	—	—	—	—	—	—	
155	Garton's 1917 ..	10.42	36.8	1.57	12.0	90.9	2.08	93.7	5.5	29.5	18.1	1.494	5.55	—	
160	Archer ..	10.38	36.0	1.56	12.4	92.2	2.07	95.5	5.5	24.0	19.0	1.516	5.6	—	
HARPER ADAMS AGRICULTURAL COLLEGE, NEWPORT, SALOP.															
171	Beaven's 1920 ..	12.78	45.0	1.61	9.7	98.0	2.00	98.6	6.0	38	19.4	—	5.6	—	
172	Webb's B. ...	12.12	43.7	1.68	11.4	93.9	1.94	96.1	6.5	37	19.7	—	5.6	—	
173	Golden Pheasant ..	12.98	44.6	1.76	9.7	96.2	2.16	96.7	7.5	32	19.5	—	5.65	—	
174	Cambridge 59/120..	12.14	—	1.79	—	—	—	—	—	—	—	—	—	—	
175	Garton's 1917 ..	12.16	43.0	1.63	11.3	92.3	2.00	94.6	6.5	37	19.5	—	5.55	—	
176	Archer ..	12.78	43.1	1.76	10.9	90.9	2.00	92.5	6.0	36	19.3	—	5.65	—	

SECTION VI. (TABLE 32.) SEASON 1923.

No.	Variety.	Barley.					Malt.					Sub-Com- mittee's Estimate of market value of Malt. in Jan., 1924. Shillings.
		Moisture per cent.	1,000 corn weight (grms.) dry.	Nitrogen per cent. on dry.	M/L as % of Dry Matter.	Extract per 448 lb. Raw Barley.	Moisture per cent.	Extract per 336 lb. Dry Malt.	Colour.	Diastatic Power. Lintner.	Cold water extract per cent.	

N.I.A.B., CAMBRIDGE.

131	Beaven's 1920 ..	15.07	41.8	1.71	8.9	100.1	1.98	97.2	4.7	36.0	19.5	54
132	Webb's B. ...	15.60	42.0	1.74	8.5	101.4	1.90	98.4	4.0	37.0	18.6	53
133	Golden Pheasant ..	14.07	37.7	1.94	8.3	101.2	1.84	96.4	4.0	37.0	18.6	60
134	Cambridge 59/120 ..	15.47	36.8	1.89	8.7	101.0	1.84	98.1	4.5	34.0	19.4	61
135	Garton's 1917, used as Control.	14.58	39.5	1.91	9.4	100.2	1.76	97.1	6.3	35.0	18.7	48
136	Beaven's 1920 ..	16.70	40.1	1.84	8.5	98.4	1.62	97.0	4.5	35.0	18.8	61
137	Webb's B. ...	16.00	37.8	1.84	9.0	100.5	1.46	98.5	4.0	36.0	18.2	60
138	Golden Pheasant ..	15.40	35.5	1.99	9.0	98.0	1.66	95.5	4.2	37.0	18.3	59
139	Cambridge 59/120 ..	14.67	37.5	1.82	8.5	100.6	1.66	96.7	4.2	35.5	18.6	60
140	Archer, used as Control	16.31	36.0	1.95	8.9	97.9	1.82	96.0	5.5	37.0	20.0	53

KIRTON, Lincs.

141	Beaven's 1920 ..	14.70	43.1	1.65	7.6	103.9	1.76	99.2	4.5	40.0	19.6	55.0
142	Webb's B. ...	14.40	40.8	1.73	8.8	103.4	1.64	99.2	4.2	38.0	18.7	53.0
143	Golden Pheasant ..	15.03	41.1	1.72	9.4	102.2	1.70	99.5	6.0	37.0	19.7	53.0
144	Golden Pheasant ..	14.47	38.1	1.87	9.0	100.7	1.80	97.0	4.7	38.0	19.2	54.0
145	Garton's 1917, used as Control.	14.42	39.1	1.77	8.6	100.2	1.78	95.9	4.5	38.0	17.7	51.0
146	Beaven's 1920 ..	14.60	38.3	1.79	8.6	101.0	1.70	97.1	5.0	40.0	20.2	51.0
147	Webb's B. ...	15.37	41.7	1.79	8.7	100.7	1.74	98.7	4.5	37.0	18.7	53.0
148	Golden Pheasant ..	15.13	38.3	1.84	9.6	101.4	2.00	99.0	6.5	37.0	19.1	53.0
149	Cambridge 59/120 ..	14.23	36.8	1.76	9.0	102.2	1.72	98.1	4.5	38.0	19.1	56.0
150	Archer, used as Control	14.68	39.0	1.90	9.4	98.8	2.00	95.7	4.5	40.0	21.2	49.0

MARKET WEIGHTON, YORKS.

151	Beaven's 1920 ..	18.15	39.0	1.34	4.7	103.6	1.62	99.6	3.5	32.0	18.2	61.0
152	Webb's B. ...	21.80	39.8	1.49	5.6	98.7	1.78	99.2	4.0	33.0	18.0	53.0
153	Golden Pheasant ..	18.35	34.4	1.54	6.1	102.0	1.58	99.5	4.2	33.0	20.8	57.0
154	Cambridge 59/120 ..	17.90	36.5	1.52	6.4	101.4	1.54	98.8	4.0	32.0	19.9	57.0
155	Garton's 1917, used as Control.	18.50	38.0	1.44	6.8	99.8	1.38	97.1	4.5	34.0	18.4	54.0
156	Beaven's 1920 ..	17.80	38.4	1.34	5.4	102.5	1.60	99.0	4.0	36.0	18.7	61.0
157	Webb's B. ...	18.00	38.4	1.46	6.3	100.5	1.58	97.8	4.2	36.0	18.5	54.0
158	Golden Pheasant ..	17.83	36.1	1.53	6.8	101.7	1.74	99.5	4.2	34.0	19.4	59.0
159	Cambridge 59/120 ..	18.10	36.6	1.48	6.4	101.1	1.84	98.9	4.0	33.0	19.7	55.0
160	Archer, used as Control	18.64	36.3	1.48	6.8	96.7	1.58	95.6	4.2	34.0	17.9	52.0

NORFOLK AGRICULTURAL STATION, NEWTON ST. FAITH'S, NORWICH.

166	Beaven's 1920 ..	14.53	41.5	1.83	7.8	101.2	1.74	96.2	4.0	37.0	19.6	60.0
167	Webb's B. ...	15.80	35.5	1.75	8.7	100.7	1.64	98.3	3.7	33.0	19.5	63.0
168	Golden Pheasant ..	14.70	31.8	1.89	8.9	101.9	1.76	98.0	4.0	34.0	20.2	59.0
169	Cambridge 50/120 ..	14.97	33.8	1.68	8.0	103.6	1.72	99.3	3.7	32.5	20.5	72.0
170	Archer, used as Control	15.09	35.0	1.86	8.8	100.2	1.90	96.9	3.7	40.0	20.0	56.0

SECTION VI.
BARLEYS FROM NATIONAL INSTITUTE OF AGRICULTURAL BOTANY.
TABLE 33. SEASON 1924.

Sample No.	Variety.	Barley.					Malt.					Market valuation by sub-committee Shillings.	
		Moisture per cent.	1,000 corn weight (grms.) dry.	Nitrogen per cent. on dry.	Making loss per cent. on dry.	Extract calculated to 448 lb. raw.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic Power. Lintner.	Cold water Extract per cent.	Barley, 448 lb., Nov., 1924.	Malt, 336 lb., Dec., 1924.
NEWTON ST. FAITH'S, NORWICH.													
166	Beaven's 1920 ..	19.50	33.3	1.279	9.4	94.2	2.34	97.6	5.2	26.0	18.9	78	100
166c	Control (Archer) ..	19.32	32.0	1.328	10.2	93.5	2.14	97.5	6.5	23.5	19.3	73	90
167	Webb's "B" ..	19.08	33.3	1.371	10.0	95.9	2.16	98.8	5.2	22.0	18.9	74	92
167c	Control (Archer) ..	18.91	32.2	1.426	10.6	93.2	2.08	96.6	6.3	27.0	19.4	71	93
169	Cambridge 59/120 ..	19.11	33.2	1.472	9.5	95.7	2.06	98.1	6.0	23.0	18.9	75	91
169c	Control (Archer) ..	19.48	30.8	1.380	10.2	93.4	1.98	97.1	5.7	24.0	18.7	74	88

TABLE 34. SEASON 1925.
Control is Plumage-Archer 1924.

Sample No.	Variety.	Barley.					Malt.					Market valuation by sub-committee. Shillings.	
		Moisture per cent.	1,000 corn weight (grms.) dry.	Nitrogen per cent. on dry.	Making loss per cent on dry.	Extract calculated to 448 lb. raw.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic Power. Lintner.	Cold water Extract per cent.		
LORD WANDSWORTH AGRICULTURAL COLLEGE. LONG SUTTON, HANTS.													
150	Beaven's Archer	16.96	41.2	1.479	11.2	95.3	2.76	97.1	9.5	20.0	23.3	65	68
150c	Control	15.84	44.1	1.453	9.7	99.0	2.54	97.7	16.0	16.5	25.1	75	67
151	Webb's Sunrise	16.38	42.0	1.479	11.6	94.6	2.50	96.1	7.5	18.0	23.9	65	68
151c	Control	16.10	44.6	1.409	12.3	95.1	2.78	97.0	14.5	17.0	25.1	75	67
152	Spratt-Archer	16.56	40.1	1.438	11.1	96.0	2.48	97.1	7.5	14.5	24.4	75	69
152c	Control	15.76	44.1	1.430	11.9	96.8	2.42	97.8	14.5	18.0	25.6	78	68
153	Archer-Goldthorpe	16.90	41.1	1.473	9.9	98.1	2.62	98.4	8.5	17.0	22.3	70	68
153c	Control	16.60	41.6	1.466	10.6	97.8	2.32	98.4	10.0	21.0	25.6	75	69
154	Beaven's No. 25	17.32	42.8	1.521	11.5	93.9	2.44	96.2	10.0	19.5	23.1	73	68
154c	Control	15.74	41.1	1.430	11.7	96.9	2.44	97.8	13.0	17.5	24.9	75	68
155	Archer	17.38	40.9	1.496	11.7	94.5	2.60	97.2	10.0	19.0	22.3	64	67
155c	Control	17.00	43.1	1.366	11.5	95.8	2.56	97.9	14.0	15.0	25.5	75	67

LEEGOMERY HOUSE, WELLINGTON, SALOP.

156	Beaven's Archer ..	16.68	40.4	1.399	10.9	98.3	2.64	99.5	7.2	21.5	22.8	75	69
156c	Control ..	16.34	42.9	1.354	9.3	102.8	2.68	101.3	8.5	22.0	22.6	77	80
157	Webb's Sunrise ..	16.68	40.4	1.423	10.9	99.4	2.68	100.4	7.0	21.5	23.7	70	69
157c	Control ..	16.24	42.4	1.383	9.3	103.2	2.56	101.9	8.0	23.5	22.8	78	80
158	Spratt-Archer ..	16.64	40.4	1.416	9.5	100.9	2.36	100.2	8.2	22.0	21.2	72	69
158c	Control ..	16.08	43.5	1.347	9.1	103.4	2.24	101.5	8.5	21.5	22.2	76	80
159	Archer-Goldthorpe ..	16.36	42.3	1.341	8.0	104.2	2.42	101.8	6.8	21.5	21.0	71	90
159c	Control ..	16.46	42.9	1.333	8.3	104.0	2.38	101.7	7.2	24.0	21.2	74	90
160	Beaven's No. 25 ..	16.26	42.4	1.383	9.1	102.3	2.72	100.8	6.5	23.0	20.1	71	90
160c	Control ..	16.08	43.2	1.356	9.5	102.3	2.54	100.9	6.8	24.0	22.6	75	90
161	Standwell ..	16.14	42.2	1.372	9.4	103.7	2.32	102.1	8.5	23.0	18.2	74	90
161c	Control ..	16.16	41.7	1.335	9.4	102.3	2.60	100.9	7.5	24.0	20.0	75	90

SECTION VI. (TABLE 34.) SEASON 1925. N.I.A.B. BARLEYS.

Sample No.	Variety.	Barley.						Malt.						Market valuation by sub-committee. Shillings.
		Moisture per cent.	1,000 corn weight (grms.) dry.	Nitrogen per cent. on dry.	Making loss per cent. on dry.	Extract calculated to 448 lb. raw.		Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic Power. Lintner°.	Cold water Extract per cent.		
														Barley, 448 lb., Nov., 1925.
														Malt, 336 lb., Dec., 1925.
NORFOLK AGRICULTURAL STATION, SPROWSTON, NORWICH.														
162	Beaven's Archer ..	18.06	35.3	1.390	10.5	97.3	2.44	99.5	8.3	19.5	24.1	73	90	
162c	Control ..	17.98	37.1	1.303	10.2	97.4	2.28	99.3	9.0	21.0	25.1	77	90	
163	Webb's Sunrise ..	17.84	35.0	1.333	10.3	97.0	1.78	98.7	9.2	20.0	24.6	70	90	
163c	Control ..	18.02	35.3	1.338	11.3	96.2	2.36	99.3	12.2	19.5	24.8	75	90	
164	Spratt-Archer ..	18.13	33.9	1.346	10.5	96.9	2.46	99.2	8.0	19.5	24.6	73	90	
164c	Control ..	18.36	33.9	1.321	11.2	94.8	2.20	98.2	9.5	21.0	25.9	71	90	
165	Archer-Goldthorpe ..	17.66	34.2	1.300	10.7	97.3	2.34	99.4	8.0	20.0	25.7	69	90	
165c	Control ..	18.23	36.2	1.301	10.3	96.5	2.30	98.7	8.3	20.0	24.4	71	90	
166	Beaven's No. 25 ..	17.46	34.5	1.426	11.7	93.8	2.20	96.5	12.0	19.0	24.9	70	90	
166c	Control ..	17.80	35.9	1.382	10.8	95.0	2.52	97.3	8.3	19.0	26.3	70	90	
167	Webb's Sunrise ..	17.98	35.7	1.324	10.8	96.7	2.36	99.2	9.0	18.5	23.9	67	90	
167c	Control ..	18.08	35.2	1.382	10.9	95.9	2.40	98.5	8.3	20.0	24.7	73	90	
168	Beaven's Archer ..	18.12	34.2	1.390	11.5	96.0	2.32	99.4	10.0	19.0	23.1	71	90	
168c	Control ..	18.28	36.3	1.367	11.1	94.7	2.36	97.7	8.7	20.0	25.6	75	90	

N.I.A.B., CAMBRIDGE.

169	Beaven's Archer ..	15.22	36.0	1.583	12.2	96.0	2.38	96.8	8.5	21.0	25.9	64	Nd	
169c	Control ..	15.84	42.2	1.636	14.3	92.4	2.64	96.4	12.0	18.5	28.2	70	"	
170	Webb's Sunrise ..	15.52	40.0	1.669	14.0	92.8	2.56	96.1	9.0	21.0	27.0	67	"	
170c	Control ..	15.32	41.1	1.704	12.3	94.4	2.28	95.4	13.7	21.5	28.2	70	67	
171	Spratt-Archer ..	15.12	37.5	1.625	12.7	95.3	2.40	96.5	10.5	19.0	27.0	67	67	
171c	Control ..	15.42	43.7	1.650	15.0	90.3	2.40	94.2	25.0	14.0	29.3	67	Nd	
172	Archer-Goldthorpe ..	14.70	39.3	1.626	12.1	96.5	2.50	96.5	14.0	16.5	27.6	60	"	
172c	Control ..	15.60	38.6	1.719	12.5	96.6	2.38	98.1	12.0	18.0	28.7	68	67	
173	Beaven's No. 25 ..	16.04	40.6	1.891	12.8	93.3	2.58	94.5	12.5	21.0	26.2	67	Nd	
173c	Control ..	15.78	39.6	1.754	15.4	89.5	2.50	94.6	16.0	21.0	29.9	67	67	

SECTION VI. (TABLE 35.) SEASON 1926. N.I.A.B. BARLEY.

Control is Plumage-Archer 1924.

Sample No.	Variety.	Barley.						Malt.						Market valuation by sub-committee. Shillings.	
		Moisture per cent.	1,000 corn weight (grms.) dry.	Nitrogen per cent. on dry.	Mating loss per cent. on dry.	Extract calculated to 448 lb. raw.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic Power.	Lintner.	Cold water Extract per cent.	Barley, 448 lb., Nov., 1926.	Malt, 336 lb., Dec., 1926.	
LORD WANDSWORTH AGRICULTURAL COLLEGE, LONG SUTTON.															
150	Beaven's Archer ..	16.2	34.8	1.421	11.6	97.5	3.50	98.8	4.5	33.2	22.7	50	59		
150c	Control (P.A. 1924)	16.6	35.4	1.368	10.3	99.0	2.60	99.4	5.3	30.7	25.3	55	61D		
151	Webb's Sunrise ..	17.1	34.7	1.385	11.1	97.5	3.28	99.2	5.2	30.7	23.8	50	58		
151c	Control ..	17.0	35.1	1.368	11.1	97.3	3.18	98.7	6.0	25.5	24.0	55	60		
152	Spratt-Archer ..	17.3	33.0	1.374	10.2	97.4	2.58	98.4	5.0	28.8	23.8	48	57		
152c	Control ..	17.0	34.8	1.306	10.2	98.1	2.74	98.6	5.0	31.6	23.9	55	59		
153	Archer-Goldthorpe ..	16.8	38.8	1.405	10.8	98.0	2.68	99.2	6.2	27.9	23.0	55	62		
153c	Control ..	17.4	35.7	1.372	10.3	97.7	3.40	98.9	5.0	31.7	24.0	55	62		
154	No. 25 ..	15.8	39.0	1.481	12.3	97.6	3.28	98.1	4.5	33.3	22.8	55	61		
154c	Control ..	17.0	36.4	1.362	10.7	97.8	3.00	99.0	5.0	30.7	21.7	55	62		
148	No. 824 ..	16.8	37.2	1.514	12.6	96.0	3.28	99.4	5.2	34.9	23.5	44D	57D		
148c	Control ..	17.6	36.8	1.368	9.9	98.0	2.84	99.0	4.7	34.4	22.0	55	65		
149	No. 825 ..	16.3	36.8	1.518	10.4	100.3	2.98	100.3	6.0	34.0	23.7	50	65		
149c	Control ..	17.1	38.2	1.339	10.3	98.1	2.98	99.1	5.0	31.3	22.0	55	65D		
146	No. 832 ..	16.0	34.2	1.338	11.5	97.6	2.96	98.5	4.7	35.8	23.8	48D	55		
147	No. 833 ..	16.2	34.7	1.460	11.3	97.7	2.74	98.6	5.0	31.2	23.2	50D	55D		

LORD WANDSWORTH AGRICULTURAL COLLEGE, LONG SUTTON.

LEEGOMERY HOUSE, WELLINGTON.

156	Beaven's Archer ..	15.6	35.0	1.498	11.1	98.6	2.68	98.5	6.0	29.4	24.5	52D	55D		
156c	Control ..	15.1	36.8	1.402	10.7	99.3	2.94	98.2	6.0	29.6	25.9	55D	65D		
157	Webb's Sunrise ..	16.0	36.0	1.495	10.6	97.3	2.76	97.2	5.0	29.5	24.6	54D	58D		
157c	Control ..	15.2	37.2	1.418	10.4	98.4	2.76	97.2	5.0	28.8	24.6	55D	57D		
158	Spratt-Archer ..	16.1	34.3	1.619	10.9	96.2	2.64	96.5	6.7	28.2	24.2	48D	56		
158c	Control ..	14.8	37.4	1.454	10.7	99.6	3.12	98.2	5.2	30.2	24.1	55D	57D		
159	Archer-Goldthorpe ..	14.0	37.5	1.410	10.6	101.3	2.82	98.7	5.2	29.8	23.1	60	63D		
159c	Control ..	15.2	35.7	1.426	9.2	99.6	2.68	97.0	5.7	28.2	24.1	55D	55D		
160	No. 25 ..	14.8	34.6	1.497	10.4	99.1	2.88	97.4	5.2	30.3	24.3	55D	58D		
160c	Control ..	15.3	31.9	1.664	11.3	96.4	2.70	96.2	7.0	38.1	24.7	55D	65D		
161	Standwell ..	15.4	38.5	1.691	11.9	99.3	3.28	100.6	8.0	35.6	25.4	55	65D		
161c	Control ..	15.4	37.3	1.446	10.8	99.8	3.26	99.2	6.0	26.2	24.5	55D	59D		

NORFOLK AGRICULTURAL STATION, SPROWSTON, NORWICH.

162	Beaven's Archer ..	15.5	28.0	1.616	12.2	97.2	3.24	98.4	6.0	38.5	25.4	37	51D		
162c	Control ..	15.3	30.8	1.571	9.6	96.8	3.28	96.1	5.0	37.4	24.9	37	51		
163	Webb's Sunrise ..	16.2	29.8	1.559	11.3	96.4	3.76	97.3	4.5	40.0	24.5	37	51		
163c	Control ..	16.0	34.4	1.479	11.5	95.5	2.74	96.4	6.5	35.6	25.0	37	51		
164	Spratt-Archer ..	16.4	30.1	1.537	11.4	97.1	2.90	98.3	4.5	33.5	25.4	37	54		
164c	Control ..	15.4	30.9	1.448	11.5	97.6	3.04	97.8	5.2	38.5	24.8	37	54		
165	Archer-Goldthorpe ..	16.4	32.9	1.568	8.3	98.4	3.08	96.4	5.4	44.4	24.1	37	55		
165c	Control ..	16.4	31.2	1.520	10.6	95.7	2.72	96.0	4.3	46.0	25.1	37	54		
166	No. 25 ..	15.8	32.6	1.618	9.7	95.9	2.82	95.7	5.3	43.0	24.1	37	54		
166c	Control ..	16.0	31.5	1.521	11.0	96.2	2.42	96.5	5.7	41.7	25.3	37	53		
167	New Cross ..	15.8	30.7	1.598	11.3	95.7	2.46	96.1	5.2	40.2	24.8	37	54		
167c	Control ..	16.4	31.9	1.543	11.4	94.5	2.64	95.7	6.2	45.0	25.4	37	52		
168	No. 824 ..	15.2	29.5	1.511	10.8	99.8	2.94	99.0	5.2	41.6	26.1	37	54		
168c	Control ..	15.7	30.5	1.469	13.3	93.8	2.66	96.5	6.3	36.6	25.4	37	52		
168A	No. 825 ..	16.4	31.8	1.580	11.9	98.4	2.98	98.3	5.3	44.1	24.6	37	57		
168Ac	Control ..	16.0	30.3	1.676	8.4	98.7	3.16	96.5	5.3	46.9	24.7	37	53		

SECTION VI. (TABLE 35.) SEASON 1926. N.I.A.B. BARLEYS.

Sample No.	Variety.	Barley.						Malt.						Market valuation by sub-committee. Shillings.	
		Moisture per cent.	1,000 corn weight (grms.) dry.	Nitrogen per cent. on dry.	Making loss per cent. on dry.	Extract calculated to 448 lb. raw.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic Power. Lintner.	Cold water Extract per cent.	Barley, 448 lb., Nov., 1926.	Malt, 336 lb., Dec., 1926.		
N.I.A.B., CAMBRIDGE.															
169	Beaven's Archer ..	16.1	35.5	1.439	9.9	99.7	3.00	98.9	3.7	39.6	22.3	58	58		
169c	Control ..	15.8	36.8	1.440	9.9	100.2	3.18	99.2	4.2	37.4	22.5	62	69		
170	Webb's Sunrise ..	15.4	35.1	1.322	11.4	99.6	2.80	99.7	4.0	31.7	22.8	58	60		
170c	Control ..	16.2	35.8	1.365	9.9	99.8	3.00	99.1	4.7	35.1	23.5	62	66		
171	Spratt-Archer ..	16.1	34.7	1.353	10.3	99.6	3.04	99.3	4.3	34.7	23.4	58	64		
171c	Control ..	16.8	35.9	1.326	10.2	98.5	2.98	98.9	4.0	37.0	22.6	65	71		
172	Archer-Goldthorpe ..	16.7	37.7	1.333	9.3	100.9	3.12	100.2	4.5	31.7	21.8	60	67		
172c	Control ..	16.0	36.9	1.313	10.8	99.6	3.32	99.7	4.0	39.2	22.8	65	65		
173	No. 25 ..	16.4	38.8	1.387	10.1	99.2	3.44	99.0	4.0	36.7	21.9	64	71		
173c	Control ..	16.1	37.4	1.357	10.4	100.0	3.12	99.7	5.0	39.2	22.9	65	80		
174	No. 824 ..	14.9	36.6	1.399	12.4	99.0	3.38	99.6	5.7	37.9	23.4	58D	51D		
174c	Control ..	15.3	37.5	1.412	11.6	98.6	3.38	98.8	5.2	41.4	23.5	65	60		
175	No. 825 ..	17.0	35.7	1.335	11.7	97.8	3.26	100.1	4.3	39.2	24.0	59	65		
175c	Control ..	17.0	36.8	1.425	10.9	97.7	3.26	99.2	4.0	43.5	21.2	65	68		
175a	No. 832 ..	13.4	35.3	1.459	12.9	98.9	3.52	99.3	6.2	40.4	22.2	59D	51		
175b	No. 833 ..	13.1	34.5	1.377	12.9	99.7	3.24	99.8	5.0	39.2	21.9	60D	51		
SEALE-HAYNE AGRICULTURAL COLLEGE, NEWTON-ABBOT, DEVON.															
176	Beaven's Archer ..	16.0	34.3	1.644	11.0	96.0	3.00	96.3	6.7	30.3	24.0	41	53		
176c	Control ..	16.1	34.1	1.738	10.8	94.8	2.90	94.9	6.3	33.7	25.1	40	53		
177	Webb's Sunrise ..	16.1	33.7	1.644	10.3	97.2	3.20	96.9	6.7	32.2	23.4	41	55		
177c	Control ..	15.6	36.9	1.702	8.9	97.7	2.84	95.2	5.7	33.7	23.6	40	53		
178	Spratt-Archer ..	16.1	33.4	1.562	10.7	96.4	2.76	96.5	4.0	29.0	23.8	41	54		
178c	Control ..	16.2	33.0	1.746	10.6	96.7	3.54	96.8	5.5	38.3	25.9	40	52		
179	Archer-Goldthorpe ..	16.2	34.4	1.528	10.5	97.3	3.06	97.3	5.7	37.9	24.3	40D	54		
179c	Control ..	16.0	34.2	1.737	11.7	95.8	3.64	96.9	5.8	36.2	24.1	40	53		
180	No. 25 ..	15.7	35.2	1.641	11.0	96.0	2.98	96.1	6.2	35.4	23.3	40	53		
180c	Control ..	15.9	34.1	1.656	10.6	96.2	2.52	96.0	5.3	34.2	24.3	40	53		
EAST ANGLIAN INSTITUTE OF AGRICULTURE, GOOD EASTER, NR. CHELMSFORD.															
181	Beaven's Archer ..	14.8	32.5	1.564	11.5	98.1	3.06	97.6	4.0	45.9	21.8	37D	54		
181c	Control ..	14.9	34.7	1.540	10.8	98.8	2.84	97.6	5.0	45.9	22.8	38D	54		
182	Webb's Sunrise ..	15.4	36.0	1.504	11.3	98.2	2.72	98.1	4.8	43.0	21.8	38D	54		
182c	Control ..	15.3	37.2	1.420	11.1	98.4	2.96	98.0	4.3	44.4	22.5	38D	55		
183	Spratt-Archer ..	14.6	32.8	1.434	11.5	99.3	2.90	98.5	4.0	36.6	23.2	38D	57		
183c	Control ..	15.1	35.1	1.405	12.6	96.6	3.40	97.7	4.0	41.7	22.7	38D	56		
184	Archer-Goldthorpe ..	14.9	38.5	1.456	10.3	100.6	3.04	98.8	4.3	42.2	21.2	41D	58		
184c	Control ..	15.2	37.0	1.415	11.0	99.3	2.76	98.6	5.3	38.5	22.8	41D	58		
185	No. 25 ..	15.0	38.6	1.428	12.7	96.8	2.56	97.9	5.0	40.9	21.7	40D	60		
185c	Control ..	14.8	36.5	1.406	11.9	99.1	3.20	99.1	4.0	41.1	23.0	41D	60		
Norwich. WINTER BARLEYS.															
140	Beaven's F97 ..	12.8	42.4	1.488	11.5	98.5	3.1	95.6	10.3	21.5	25.2	37D			
140c	Control(Squarehead) ..	13.4	35.9	1.469	8.9	102.4	3.2	97.2	4.3	37.0	19.8	37D			
141	Beaven's F112 ..	12.8	32.5	1.341	10.0	100.7	3.0	95.9	5.5	33.3	22.3	37D			
141c	Control ..	12.9	35.1	1.403	10.2	100.6	2.9	96.3	5.0	33.3	21.7	37D			
142	Plumage-Archer (Winter Sown) ..	14.1	37.3	1.341	9.8	104.1	2.8	100.7	5.0	35.0	23.0	60D			
142c	Control ..	13.7	34.6	1.441	9.3	100.2	2.8	95.8	5.2	37.0	21.5	37D			
Long Sutton.															
143	Beaven's F97 ..	15.4	40.8	1.504	9.8	93.8	2.8	92.3	7.0	37.0	25.6	36			
143c	Squarehead ..	16.0	33.6	1.415	12.3	93.0	2.5	94.8	10.5	26.0	22.9	37D			
144	Beaven's F112 ..	16.0	26.1	1.441	12.3	87.3	3.1	90.0	9.5	37.2	27.1	35			
145	Plumage-Archer 1924 (Winter sown) ..	16.4	38.9	1.367	10.0	99.0	3.1	98.7	5.5	35.8	22.5	65	86		

SECTION VI. (TABLE 38.) SEASON 1927.
BARLEYS FROM NATIONAL INSTITUTE OF AGRICULTURAL BOTANY.
Control to spring-sown barleys is Plumage-Archer 1924.

Sample No.	Variety.	Barley.					Malt.							Market Valuation by Sub-committee, Shillings.	
		Moisture, per cent.	1,000 corn weight (grams) dry.	Nitrogen, per cent. on dry.	Milling Loss on dry.	Barley. Extract from 443 lb. raw.	Moisture, per cent.	Extract per 336 lb. on dry.	Colour.	Diastatic Power, Lindner.	Cold Water Extract, per cent.	Permanently Soluble N. per cent. on dry.	Barley, per 443 lb.	Malt, per 336 lb.	
NORFOLK AGRICULTURAL STATION, SPOWSTON, NORWICH.															
Spring sown.															
182	Beaven's Archer	18.7	-	1.37	10.0	97.5	2.7	99.9	4.5	41.0	19.4	-	63	80	
189c	Control	18.8	-	1.20	6.3	102.2	2.7	100.8	5.5	40.0	20.0	-	70	80	
183	Webb's Sunrise	18.0	-	1.29	8.3	102.1	2.6	101.9	5.7	42.0	22.8	-	63	80	
183c	Control	17.9	-	1.24	9.0	101.2	2.8	101.7	6.5	39.5	22.2	-	70	80	
164	Spratt-Archer	17.8	-	1.33	9.5	99.6	2.8	100.4	5.5	39.0	22.1	-	70	80	
164c	Control	17.9	-	1.26	8.1	102.3	2.8	101.8	6.3	39.0	22.4	-	70	80	
185	Archer Goldthorpe	18.8	-	1.38	8.0	100.5	3.0	100.9	5.5	43.5	21.0	-	63	90	
185c	Control	18.7	-	1.29	8.6	100.8	2.7	101.6	6.5	40.0	22.7	-	70	90	
186	Beaven's 25	18.1	-	1.34	9.1	100.6	2.9	101.4	7.3	40.0	20.9	-	68	80	
186c	Control	18.1	-	1.27	8.6	101.4	2.7	101.7	5.3	39.5	21.0	-	68	80	
187	New Cross	18.9	-	1.31	8.5	100.3	2.7	101.3	6.0	37.5	22.1	-	63	80	
187c	Control	19.5	-	1.30	8.1	99.9	2.8	101.3	5.0	43.5	20.8	-	68	80	
188	824	19.4	-	1.44	8.6	100.2	2.8	102.0	5.3	48.5	21.5	-	68D	80	
188c	Control	18.1	-	1.30	8.1	102.3	2.8	101.9	4.0	48.5	21.5	-	70	80	
188A	825	17.9	-	1.42	9.8	100.6	2.8	101.9	7.3	45.0	22.3	-	63	80	
188Ag	Control	18.6	-	1.28	8.6	100.8	2.7	101.7	6.0	45.0	22.9	-	70	80	
Autumn sown															
142	Plumage-Archer	19.9	33.6	1.19	14.9	92.2	3.3	101.3	4.3	36.0	19.6	-	70	81	
142c	F.112	21.5	30.6	1.31	8.6	90.4	3.3	94.7	4.3	40.5	18.5	-	35	(1)	
193	Selected Archer	21.4	-	1.32	10.0	95.2	2.9	101.0	6.0	-	19.8	-	48	72	
193c	F.112	20.9	30.2	1.26	8.3	91.4	3.3	94.7	7.0	38.0	19.1	-	35	(1)	
194	Spratt-Archer	20.7	-	1.32	9.9	96.1	3.5	100.7	5.3	46.5	22.0	-	48	72	
194c	F.112	21.7	32.3	1.34	7.5	92.5	3.2	95.0	5.3	38.0	19.4	-	35	(1)	
195	Webb's Sunrise	21.8	-	1.38	10.6	93.7	3.3	100.5	6.3	40.0	22.1	-	48	68	
195c	F.112	21.8	31.1	1.25	8.8	89.3	3.3	94.2	6.7	36.0	20.5	0.444	35	(1)	

NATIONAL INSTITUTE OF AGRICULTURAL BOTANY, CAMBRIDGE.

NATIONAL INSTITUTE OF AGRICULTURAL BOTANY, CAMBRIDGE.															
Spring sown.															
169	Beaven's Archer	17.2	—	1.64	9.3	99.0	2.9	98.8	4.7	60.5	18.9	—	60	72	
169c	Control	17.2	—	1.55	7.9	102.6	3.0	100.9	4.7	55.5	19.1	—	70	81	
170	Webb's Sunrise	17.9	—	1.62	8.7	98.1	3.2	98.1	4.7	60.0	19.0	—	52	72	
170c	Control	16.9	—	1.56	8.0	102.5	3.0	100.7	4.7	56.0	19.7	—	70	81	
171	Spratt-Archer	17.7	37.3	1.60	7.6	101.0	2.9	99.6	4.5	53.0	19.3	—	60	72	
171c	Control	17.7	—	1.54	7.8	101.1	3.0	99.9	4.7	52.5	19.3	—	70	81	
172	Archer-Goldthorpe	17.6	—	1.65	7.1	101.8	3.0	99.7	4.5	51.0	18.8	—	70	81	
172c	Control	17.0	—	1.55	8.3	102.3	2.9	100.8	5.3	56.5	19.6	—	70	81	
173	Beaven's 25	17.1	—	1.71	8.4	99.8	3.0	98.6	3.5	78.0	18.9	—	70	81	
173c	Control	17.3	—	1.58	8.7	100.9	2.9	100.2	4.3	56.0	19.3	—	70	81	
174	824	17.8	—	1.75	8.4	98.7	3.1	98.3	5.5	63.0	20.6	—	60	72	
174c	Control	17.6	—	1.58	7.8	100.9	3.1	99.6	5.5	53.5	19.5	—	70	81	
175	825	17.2	—	1.64	8.7	100.9	3.0	100.1	4.7	62.0	20.4	—	60	72	
175c	Control	17.1	—	1.60	7.9	101.7	3.0	99.9	4.7	56.5	19.3	—	70	81	
Autumn sown.															
199	B.244	17.6	32.8	1.51	9.3	94.2	3.4	94.6	4.0	45.0	16.0	1.383	40	(1)	
199c	B.43	17.2	—	1.73	7.4	93.6	3.3	91.4	4.0	42.0	15.6	—	35	—	

EAST ANGLIAN INSTITUTE OF AGRICULTURE, GOOD EASTER, NR. CHELMSFORD.

<i>Spring sown.</i>																	
181	Beaven's Archer	18.0	—	1.49	10.7	96.9	2.9	99.3	5.7	46.0	21.8	—	52D	Barleys so damaged that malts could not be valued as in judges' opinion they were unsaleable material. Ignoring damages placed in grade 6 with malts valued 70/-.			
181c	Control	18.3	—	1.40	7.1	101.5	2.9	100.4	5.0	47.5	22.3	—	53D				
182	Webb's Sunrise	17.7	—	1.48	11.2	97.0	2.9	99.6	7.2	41.5	22.8	—	48D				
182c	Control	18.3	—	1.45	9.7	97.6	3.1	100.2	7.5	41.0	22.3	—	53D				
183	Spratt-Archer	17.4	—	1.37	11.0	97.8	3.1	99.8	7.2	34.5	24.7	—	52D				
183c	Control	18.0	—	1.42	9.8	98.6	3.1	100.0	7.5	41.0	21.4	—	53D				
184	Archer Goldthorpe	17.0	—	1.50	9.9	100.4	3.2	100.7	7.5	41.5	21.5	—	52D				
184c	Control	22.1	Rejected.				Not Malted.										
185	Beaven's 25	17.1	—	1.48	11.0	99.4	3.4	101.0	7.2	41.5	20.9	—	53D				
185c	Control	17.3	—	1.42	10.6	99.4	3.2	100.8	6.5	47.0	23.1	—	53D				
186	824	17.7	—	1.54	11.7	97.5	3.1	100.6	7.7	46.5	23.0	—	48D				
186c	Control	17.8	—	1.42	10.4	99.0	3.2	100.8	7.2	38.5	23.2	—	52D				
187	825	17.6	—	1.48	11.7	98.7	3.1	101.7	8.5	51.5	24.8	—	48D				
187c	Control	17.4	—	1.36	10.8	99.3	3.1	101.1	8.3	41.0	23.1	—	53D				

Sample No.	Variety.	Barley.					Malt.							Market Valuation by Sub-committee. Shillings.	
		Moisture, per cent.	1,000 corn weight (grams) dry.	Nitrogen, per cent. on dry.	Making Loss on dry barley.	Extract from 448 lb. raw.	Moisture, per cent.	Extract per 336 lb. on dry.	Colour.	Diastatic Power. Lintner.	Cold Water Extract, per cent.	Permanently Soluble N. per cent. on dry.	Barley per 448 lb.	Malt per 336 lb.	
Autumn sown.															
188	Plumage-Archer	19.4	37.5	1.35	9.6	96.7	3.1	99.6	7.5	41.5	20.1	—	48	72	
188c	F.112	17.2	32.8	1.52	11.2	90.5	3.3	92.6	6.5	51.5	21.3	—	35	(3)	
189	Sunrise	18.2	—	1.38	10.4	97.2	3.1	99.5	7.8	37.5	22.6	—	48	68	
189c	F.112	17.9	32.8	1.48	11.8	90.3	3.4	93.7	7.5	47.5	21.1	—	35	(1)	
190	Spratt-Archer	17.6	33.6	1.64	11.7	95.1	3.3	98.1	5.8	48.0	21.7	—	48	68	
190c	F.112	18.2	34.0	1.59	9.0	91.6	3.2	92.4	8.2	36.0	19.9	0.514	35	(3)	
Spring sown.															
LORD WANDSWORTH AGRICULTURAL COLLEGE, LONG SUTTON, HANTS.															
150	Beaven's Archer	22.1	—	1.48	9.1	92.8	3.0	98.0	8.3	31.5	18.1	—	43D	70D	
150c	Control	21.3	—	1.34	8.5	95.8	3.2	99.8	7.3	35.0	18.9	—	52D	80	
151	Webb's Sunrise	21.4	—	1.50	10.6	92.3	3.3	98.6	6.3	44.0	18.5	—	44D	70D	
151c	Control	21.1	—	1.38	7.9	97.1	2.9	100.2	6.5	41.0	19.5	—	53	75D	
152	Spratt-Archer	22.2	—	1.34	8.9	94.3	3.0	99.7	5.8	36.0	20.9	—	44	75D	
152c	Control	20.9	—	1.33	8.1	96.9	2.9	99.9	7.3	40.5	20.4	—	53D	75D	
153	Archer-Goldthorpe	20.8	—	1.40	7.9	96.9	3.0	99.7	5.5	45.0	19.4	—	53	80	
153c	Control	20.1	—	1.38	9.1	97.2	3.1	100.3	7.0	43.0	20.5	—	53	75D	
154	Beaven's 25	19.8	—	1.61	10.4	95.8	3.2	99.0	7.5	42.5	21.5	—	53D	70D	
154c	Control	20.0	—	1.42	9.4	96.5	3.1	100.0	5.8	44.0	22.1	—	53D	75D	
148	824	20.8	—	1.50	9.7	95.4	3.2	100.0	6.8	50.0	21.6	—	42D	70D	
148c	Control	20.2	—	1.40	8.2	97.9	2.8	100.3	7.2	41.0	19.8	—	53	80	
149	825	21.2	—	1.44	8.4	95.8	3.0	99.5	8.0	34.0	19.0	—	44D	70D	
149c	Control	20.5	—	1.37	7.8	97.6	3.0	99.8	6.0	41.0	18.2	—	53	80	
Autumn sown.															
143	F.97	19.2	—	1.43	8.7	91.9	3.8	93.4	8.3	42.0	19.5	—	35	(1)	
143c	Garton's Squarehead	19.3	—	1.52	6.8	93.3	3.5	93.1	4.7	37.5	16.3	—	35	(2)	
144	F.112	18.9	37.2	1.34	8.2	91.6	3.7	93.0	6.0	43.0	19.3	—	35	(1)	
144c	G. Squarehead	19.1	—	1.48	7.2	94.3	3.4	94.2	5.5	36.0	16.7	—	35	(2)	
145	Plumage-Archer	18.6	41.5	1.41	8.1	98.7	3.3	98.9	5.7	42.5	20.0	—	68	75	
145c	G. Squarehead	19.2	—	1.59	6.8	93.6	3.3	93.2	6.3	39.0	16.7	—	35	(2)	
Spring sown.															
SEALE HAYNE AGRICULTURAL COLLEGE, NEWTON ABBOT, DEVON.															
176	Beaven's Archer	18.7	—	1.52	—	—	—	—	—	—	—	—	—	—	
176c	Control	17.7	—	1.51	—	—	—	—	—	—	—	—	—	—	
177	Webb's Sunrise	18.9	—	1.55	—	—	—	—	—	—	—	—	—	—	
177c	Control	18.5	—	1.49	—	—	—	—	—	—	—	—	—	—	
178	Spratt-Archer	18.6	—	1.42	—	—	—	—	—	—	—	—	—	—	
178c	Control	18.4	—	1.50	—	—	—	—	—	—	—	—	—	—	
179	Archer-Goldthorpe	18.8	—	1.52	—	—	—	—	—	—	—	—	—	—	
179c	Control	18.2	—	1.56	—	—	—	—	—	—	—	—	—	—	
180	Beaven's 25	18.3	—	1.68	—	—	—	—	—	—	—	—	—	—	
180c	Control	19.5	—	1.56	—	—	—	—	—	—	—	—	—	—	
Spring sown.															
HARPER ADAMS AGRICULTURAL COLLEGE, NEWPORT, SALOP.															
156	Beaven's Archer	18.1	—	1.56	9.5	98.1	3.1	99.4	4.5	56.5	19.2	—	75	64	
156c	Control	17.9	—	1.49	8.5	100.8	3.0	100.6	4.7	55.5	20.7	—	80	70	
157	Webb's Sunrise	18.5	—	1.56	8.9	98.4	3.0	99.3	5.5	55.5	19.5	—	75	64	
157c	Control	18.0	—	1.49	8.4	100.9	2.9	100.8	5.0	54.0	20.7	—	80	70	
158	Spratt-Archer	18.3	—	1.46	8.6	101.0	2.9	101.4	5.8	48.5	21.0	—	80	68	
158c	Control	18.1	39.3	1.49	8.1	101.6	2.9	101.2	5.0	57.5	20.4	—	80	70	
159	Archer-Goldthorpe	18.1	—	1.54	8.1	101.4	3.0	101.0	5.3	55.0	19.5	—	75	65	
159c	Control	17.7	—	1.50	9.1	100.8	3.0	101.0	5.3	57.5	20.7	—	80	65	
160	Beaven's 25	17.7	—	1.59	9.2	100.3	2.9	100.3	5.7	55.0	20.2	—	75	65	
160c	Control	18.1	—	1.48	8.9	100.8	2.7	101.3	6.5	52.0	20.8	—	75D	70	
191	824	18.3	—	1.58	8.5	101.6	3.1	101.9	5.3	54.5	21.7	—	80	68	
191c	Control	18.0	—	1.54	8.6	100.7	3.2	100.8	5.0	52.0	20.4	—	80	65	
192	825	18.4	—	1.53	8.7	101.5	3.0	102.2	5.7	56.5	20.7	—	80	68	
192c	Control	18.4	—	1.47	8.2	101.3	3.2	101.4	5.5	58.0	20.8	—	80	65	
161	Standwell	17.7	41.1	1.78	9.1	101.0	2.8	101.2	7.3	52.0	21.2	0.61	80	60	
161c	Control	18.1	—	1.45	8.3	101.9	2.8	101.8	4.5	52.0	20.6	—	80	70	

VALUER'S NOTES ON AUTUMN-SOWN BARLEYS. HARVESTED 1927.

(1) The Committee considered that the range of barleys here possibilities, and that it would be advisable that a plot, or plots, be laid down for experimental maltings and brewings. Malsters for sale could not give a value to these samples, as their appearance makes them unsaleable. They could not find a customer except for experimental purposes.

(2) The Committee did not care for these as malting barleys, and without further information cannot see a future for them.

(3) The Committee did not like these, 199 C, B.43 ex Cambridge, turned out a very bad malter this season. Black ends.

SECTION VI. (TABLE 37.) SEASON 1928.
BARLEYS FROM NATIONAL INSTITUTE OF AGRICULTURAL BOTANY.

Control is Plumage-Archer 1924.

		Barley.						Malt.						Market valuation by Subcommittee. Shillings.	
Sample No.	Variety.	Moisture, per cent.	1,000 corn weight (grams) dry.	Nitrogen, per cent. on dry.	Malting loss, per cent. on dry.	Extract calculated to 448 lb raw.	Moisture, per cent.	Extract, per 336 lb. on dry.	Colour.	Diastatic Power. Lintner.	Cold Water Extract, per cent.	Permanently Soluble N, per cent. on dry.	Barley, per 448 lb.	Malt, per 336 lb.	
NORFOLK AGRICULTURAL STATION, SPROWSTON, NORWICH.															
<i>Spring sown.</i>															
164	Sp. Archer	15.0	30.5	1.34	9.9	102.6	3.1	100.4	2.8	37.5	22.2	0.50	49	74	
164c	Control	14.4	33.9	1.28	10.2	104.0	3.0	101.4	3.0	40.0	21.6	*	50	70	
168	824	15.0	34.0	1.32	10.5	103.0	3.3	101.5	3.0	35.0	22.1	0.47	49	72	
168c	Control	15.0	34.0	1.27	9.0	104.4	3.1	101.3	2.7	36.5	22.6	*	50	70	
168A	825	16.0	31.6	1.25	9.7	103.6	3.1	102.5	3.0	31.0	23.7	0.43	49	72	
168c	Control	14.2	32.1	1.24	9.3	104.6	3.1	100.9	3.2	33.0	22.8	*	50	70	

NATIONAL INSTITUTE OF AGRICULTURAL BOTANY, CAMBRIDGE.

<i>Spring sown.</i>														
171	Sp. Archer	14.3	34.6	1.79	9.1	101.1	3.0	97.4	2.3	58.5	20.2	0.56	39	58
171c	Control	14.2	37.4	1.77	9.0	104.1	3.1	96.7	2.3	63.0	19.8	*	39	58
174	824	15.0	36.9	1.86	9.4	102.7	3.0	98.7	2.3	77.0	21.3	0.60	39	58
174c	Control	14.5	37.8	1.75	9.0	103.7	3.1	97.7	2.3	64.0	19.6	*	39	58
175	825	14.7	36.5	1.79	10.0	102.4	3.2	99.6	2.5	72.0	21.8	0.60	39	58
175c	Control	13.4	37.7	1.70	9.5	104.5	3.1	97.8	2.5	64.0	20.7	*	39	58

NATIONAL INSTITUTE OF AGRICULTURAL BOTANY, CAMBRIDGE.

Autumn sown.														
200	Carter's 6-row Winter	16.4	40.8	1.57	6.4	99.4	3.1	95.3	2.1	37.0	16.9	—	37	54
200c	B.244	16.8	32.5	1.48	7.8	101.3	3.1	99.2	2.1	45.0	17.3	0.42	40	72
201	833 Archer	16.6	—	1.83	Not	—	—	—	—	—	—	—	39	—
					Malted									
201c	B.244	15.3	—	1.44	„	—	—	—	—	—	—	—	43	—

EAST ANGLIAN INSTITUTE OF AGRICULTURE, GOOD EASTER, NR. CHELMSFORD.

<i>Spring sown.</i>														
183	Sp. Archer	14.9	31.0	1.40	10.0	102.1	3.0	100.3	3.0	38.0	21.6	—	39	60
183c	Control	15.5	33.7	1.38	11.1	102.0	3.4	99.6	2.5	51.0	21.1	—	39	60
186	824	15.5	33.2	1.46	—	—	3.0	100.4	3.5	45.0	21.6	—	39	60
186c	Control	15.2	35.4	1.42	12.4	99.0	3.1	100.1	2.7	48.5	21.7	—	39	60
187	825	15.3	35.6	1.46	9.9	101.8	3.0	101.3	3.0	46.5	21.5	—	40	60
187c	Control	14.3	37.2	1.35	9.6	103.7	3.0	100.2	2.7	44.5	20.8	—	40	60

Barleys so badly dressed that Malting Loss figures are useless.

LORD WANDSWORTH AGRICULTURAL COLLEGE, LONG SUTTON, NR. BASINGSTOKE, HANTS.

Spring sown.														
152	Sp. Archer	21.7	36.1	1.39	8.3	95.7	3.1	100.8	2.5	34.0	19.8	—	38	70
152c	Control	20.1	38.9	1.40	8.5	98.3	3.1	100.8	2.5	41.0	19.4	—	39	68
148	824	21.3	38.2	1.45	8.8	95.7	3.1	101.5	2.7	48.0	20.9	—	38	70
148c	Control	20.0	40.0	1.43	8.7	97.4	3.1	100.8	2.7	42.5	19.8	—	39	68
149	825	22.0	37.2	1.45	8.9	94.8	3.3	101.8	2.5	46.0	20.2	—	38	70
149c	Control	20.6	39.0	1.38	8.1	96.1	3.0	101.1	2.7	37.5	21.1	—	39	68

* Means of Permanently Soluble Nitrogen in Malts from Plumage-Archer Barleys :—
Norfolk Agric. Station, 0.46 per cent. on dry.
N.I.A.B., 0.54 " "

SECTION VI. (TABLE 37.) SEASON 1928. N.I.A.B. BARLEYS.

Sample No.	Variety.	Barley.						Malt.						Market valuation by sub-committee. Shillings.	
		Moisture, per cent.	1,000 corn weight (grams) dry.	Nitrogen, per cent. on dry.	Malting Loss, per cent. on dry.	Extract calculated to 448 lb. raw.		Moisture, per cent.	Extract per 336 lb. on dry.	Colour.	Diastatic Power. Lintner.	Cold Water Extract. per cent.	Permanently Soluble N, per cent. on dry.	Barley, per 448 lb.	Malt, per 336 lb.
196	Sp. Archer	15.4	38.0	1.62	10.1	101.4		3.1	99.1	3.5	47.5	23.4	—	39	56
196c	Control ..	15.1	41.8	1.66	10.5	101.3		3.1	98.8	4.0	53.5	23.5	—	39	56
197	824 ..	15.3	39.1	1.73	9.6	102.1		3.1	100.0	3.7	63.5	22.6	—	39	56
197c	Control ..	14.8	43.2	1.63	9.9	102.4		3.0	99.3	3.2	52.0	22.0	—	39	56
198	825 ..	15.6	40.8	1.72	10.1	101.2		3.2	100.7	3.3	60.0	23.0	—	39	56
198c	Control ..	14.6	42.5	1.67	9.9	102.3		3.2	99.8	3.8	51.0	22.4	—	39	56

SOMERSET FARM INSTITUTE, CANNINGTON, NR. BRIDGEWATER.

Spring sown.

168	Sp. Archer	18.1	38.9	1.35	9.4	101.2		3.2	102.5	3.2	35.5	21.2	0.50	45	68
158c	Control ..	16.9	40.5	1.31	8.8	104.3		3.0	103.1	3.3	35.5	21.9	0.50	47	64
191	824 ..	18.3	41.4	1.42	8.5	102.0		3.1	102.4	3.0	44.5	21.6	0.54	45	67
191c	Control ..	16.6	41.0	1.33	8.9	104.2		3.2	102.8	3.3	37.5	21.4	0.50	47	64
192	825 ..	17.7	38.4	1.40	9.0	103.4		2.9	103.7	3.2	40.0	21.1	0.52	45	67
192c	Control ..	16.9	40.6	1.27	7.9	105.6		3.0	103.6	3.2	36.5	21.0	0.52	47	66

HARPER ADAMS AGRICULTURAL COLLEGE, NEWPORT, SALOP.

Spring sown.

168	Sp. Archer	18.1	38.9	1.35	9.4	101.2		3.2	102.5	3.2	35.5	21.2	0.50	45	68
158c	Control ..	16.9	40.5	1.31	8.8	104.3		3.0	103.1	3.3	35.5	21.9	0.50	47	64
191	824 ..	18.3	41.4	1.42	8.5	102.0		3.1	102.4	3.0	44.5	21.6	0.54	45	67
191c	Control ..	16.6	41.0	1.33	8.9	104.2		3.2	102.8	3.3	37.5	21.4	0.50	47	64
192	825 ..	17.7	38.4	1.40	9.0	103.4		2.9	103.7	3.2	40.0	21.1	0.52	45	67
192c	Control ..	16.9	40.6	1.27	7.9	105.6		3.0	103.6	3.2	36.5	21.0	0.52	47	66

SECTION VI. (TABLE 38.) SEASON 1929.

BARLEYS FROM NATIONAL INSTITUTE OF AGRICULTURAL BOTANY.

Control is Spratt-Archer 37/6, except 110C.

Sample No.	Variety.	Barley.								Malt.						Market valuation by Sub-Committee. Shillings.	
		Manurial Treatment.	Moisture per cent.	1000 corn weight (grams) dry.	Nitrogen per cent. on dry.	Making loss per cent. on dry.	Extract calculated to 448 lb. raw.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic Power. Lintner.	Cold water extract per cent.	Total soluble Nitrogen per cent. on dry.	Barley per 448 lb.	Malt per 336 lb.		
NORFOLK AGRICULTURAL STATION, SPROWSTON, NORWICH.																	
101	824	Normal	14.7	39.0	1.44	9.6	104.5	3.3	101.6	3.3	35.5	20.8	0.57	39	68		
101 C	Control	"	14.3	38.4	1.34	9.3	105.0	3.5	101.4	4.0	26.0	22.6	0.53	39	68		
102	825	"	14.8	38.1	1.43	9.8	103.8	3.5	101.3	3.8	36.0	21.3	0.58	39	68		
102 C	Control	"	14.0	39.1	1.38	11.1	103.0	3.3	101.1	4.2	28.5	22.2	0.54	39	68		
103	824	Intensive	14.5	39.2	1.48	9.7	104.6	3.2	101.7	3.5	38.0	21.7	0.60	39	68		
103 C	Control	"	14.2	39.4	1.35	9.4	104.6	3.1	101.0	4.0	26.0	22.1	0.50	39	68		
104	825	"	14.8	38.3	1.45	9.8	103.7	3.1	101.2	4.0	35.0	21.6	0.56	39	68		
104 C	Control	"	14.0	39.7	1.40	9.5	104.1	3.2	100.3	4.8	25.5	21.5	0.52	39	68		
105	Spratt Archer 37/4 Irish																
	Stock	Normal	14.5	38.5	1.35	9.0	105.9	3.1	102.2	3.3	29.5	21.2	0.53	39	68		
105 C	Control	"	14.2	38.2	1.36	9.0	105.7	3.0	101.6	3.8	27.0	22.1	0.52	39	68		

Valuer's Note: Very disappointing for Norfolk.

Very similar, No. 102, slightly brighter than its Control, 105C a shade brighter than 105.

NATIONAL INSTITUTE OF AGRICULTURAL BOTANY, CAMBRIDGE.

106	824	Normal	13.1	39.8	1.51	9.2	106.1	2.9	100.9	3.2	44.0	20.7	0.55	42	73		
106 C	Control	"	13.3	38.8	1.47	8.6	106.9	3.3	101.0	3.0	35.5	20.1	0.50	44	73		
107	825	"	13.1	38.9	1.46	8.3	108.6	3.2	102.4	3.3	40.0	20.3	0.55	42	73		
107 C	Control	"	12.9	40.6	1.44	8.2	108.3	3.1	101.7	3.2	34.5	19.4	0.42	43	73		
108	824	Intensive	13.1	41.7	1.61	9.0	105.8	3.3	100.4	3.5	45.5	20.9	0.55	43	73		
108 C	Control	"	13.2	41.5	1.55	8.2	107.4	3.0	101.2	3.3	35.5	19.7	0.51	42	73		
109	825	"	13.4	39.2	1.55	9.3	106.2	3.2	101.5	3.0	47.0	20.9	0.57	42	73		
109 C	Control	"	13.4	39.0	1.48	8.2	106.6	3.2	100.6	2.8	34.5	19.9	0.42	42	73		
110	Archer (disease free)																
110 C	Archer (ordinary stock)	Normal	13.5	39.6	1.39	9.1	106.0	2.9	101.2	3.5	34.5	18.8	0.43	44	73		
		"	13.6	38.6	1.39	8.6	107.2	3.0	101.9	3.2	37.0	18.9	0.47	44	73		

Valuer's Note: Good level lot of mild ale quality.

Really beautiful malts, no differences noted.

131	B 244	Winter sown	14.6	34.7	1.79	8.7	97.8	3.1	94.0	2.5	45.5	17.4	0.46	32	—		
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Valuer's note.

Worth going on with. Distillers or vinegar barley.

Better than F112.

Nearer to two-rowed malt, hence not so good for drainage.

EAST ANGLIAN INSTITUTE OF AGRICULTURE, GOOD EASTER, NR. CHELMSFORD.

111	824	Normal	15.1	38.9	1.50	9.4	102.7	3.2	100.1	3.2	42.5	19.9	0.54	48	74		
111 C	Control	"	14.8	38.6	1.32	8.2	104.8	2.9	100.5	3.8	27.5	20.3	0.47	48	74		
112	825	"	15.4	40.0	1.30	9.0	105.1	3.3	102.5	3.0	31.0	20.4	0.50	47	74		
112 C	Control	"	15.3	40.6	1.23	8.3	105.1	3.3	101.5	3.3	27.5	20.4	0.48	48	74		
113	824	Intensive	15.4	40.3	1.32	9.0	105.9	3.2	103.3	4.2	30.0	20.4	0.55	48	74		
113 C	Control	"	16.1	39.8	1.30	8.3	105.1	3.2	102.5	4.0	27.0	20.2	0.50	48	74		
114	825	"	16.1	39.5	1.23	9.8	104.6	2.8	102.6	3.8	33.0	20.1	0.49	48	74		
114 C	Control	"	15.2	40.7	1.27	8.3	105.2	3.0	101.5	4.2	29.5	21.2	0.48	48	74		

Extremely good and very uniform. Nos. 111 and 114 silkier in skin. Finest mild ale barleys of year. Finest pale ale malts of season; no differences noted.

SECTION VI, (TABLE 38). SEASON 1929. N.I.A.B. BARLEYS.

Sample No.	Variety	Barley.							Malt.							Market valuation by Sub-Committee. Shillings.	
		Manurial Treatment.	Moisture per cent.	1000 corn weight (grams) dry.	Nitrogen per cent. on dry.	Making loss per cent. on dry.	Extract calculated to 448 lb. raw.		Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic Power, Lintner.	Cold water extract per cent.	Total soluble Nitrogen per cent. on dry.		Barley per 448 lb.	Malt per 336 lb.
119	824	Normal	15.4	35.2	1.59	9.6	103.4		3.1	101.4	3.5	48.0	20.3	0.61		32	66
119 C	Control	"	15.5	33.8	1.56	9.4	101.5		3.3	99.5	4.3	42.5	20.0	0.60		32	66
120	825	"	15.5	34.0	1.65	9.8	102.9		3.5	101.3	4.2	44.5	21.8	0.87		32	66
120 C	Control	"	15.8	32.3	1.65	9.4	101.8		3.1	99.6	3.5	43.5	21.7			32	65
121	824	Intensive	15.4	33.8	1.90	10.2	99.7		3.4	98.4	4.3	53.0	21.6	0.69		32	60
121 C	Control	"	15.5	30.7	1.89	10.2	99.1		3.4	97.9	4.2	44.5	21.4			32	60
122	825	Intensive	15.3	32.7	1.90	10.5	99.3		3.4	98.2	4.5	50.5	21.4	0.73		32	60
122 C	Control	"	15.5	31.8	1.85	10.5	97.9		3.3	97.1	4.0	45.0	21.1			32	60

Grinding barley.

No differences noted between Nos. 119 and 120 and their controls. Nos. 121 and 122 not suitable malts as they are small and thin, though quality seems good.

LORD WANDSWORTH AGRICULTURAL COLLEGE, LONG SUTTON, BASINGSTOKE, HANTS.

115	824	Normal	15.4	37.8	1.29	9.8	103.1		2.9	101.4	4.5	26.5	22.4	0.51		39	73
115 C	Control	"	15.6	36.8	1.26	8.3	104.1		3.0	100.9	5.3	22.5	21.9	0.48		39	73
116	825	"	15.8	36.0	1.23	9.4	104.6		2.8	102.0	3.7	28.5	21.6	0.52		39	73
116 C	Control	"	15.8	36.8	1.24	8.0	105.7		3.0	102.4	3.8	27.5	20.3			39	73
117	824	Intensive	15.5	37.9	1.27	9.8	103.1		3.3	101.7	4.2	23.5	19.9	0.51		39	73
117 C	Control	"	16.0	37.4	1.27	8.6	104.3		3.2	101.9	5.7	22.5	22.2	0.50		39	73
118	825	"	15.4	37.2	1.26	9.0	104.7		3.1	102.1	5.3	22.0	21.2			39	73
118 C	Control	"	15.4	37.6	1.28	8.9	104.2		3.1	101.4	6.0	22.5	21.2			39	73

Very level lot.

Fine pale ale malt. No differences noted.

SOMERSET FARM INSTITUTE, CANNINGTON, BRIDGEWATER.

123	824	Normal	15.2	41.2	1.51	9.5	104.5		3.0	102.2	4.0	34.0	22.0	0.59		40	74
123 C	Control	"	15.3	38.8	1.46	8.6	103.9		2.7	100.7	5.0	29.0	22.4	0.55		40	74
124	825	"	15.4	41.3	1.54	9.2	103.5		2.8	101.1	4.7	38.0	22.2	0.61		40	74
124 C	Control	"	15.1	38.9	1.44	8.8	103.9		2.7	100.7	4.5	29.0	21.4			40	74
125	824	Intensive	15.3	41.8	1.49	9.1	104.4		3.1	101.7	5.0	35.0	21.8	0.55		40	73
125 C	Control	"	15.4	40.0	1.45	9.0	103.2		2.9	100.6	4.3	28.5	22.7	0.56		40	73
126	825	"	15.3	42.0	1.47	9.2	103.5		3.0	101.0	4.0	33.0	22.5	0.58		40	73
126 C	Control	"	15.6	40.2	1.46	9.2	102.4		3.5	100.2	3.2	34.5	23.0			40	73

All hard and steely. Nos. 124 C and 126 C slightly inferior.

Very little difference. Intensive manuring tends to reduce superfine complexion.

HARPER ADAMS AGRICULTURAL COLLEGE, NEWPORT, SALOP.

127	824	Normal	17.3	37.7	1.33	9.5	100.3		3.0	100.5	4.5	30.0	22.0	0.52		41	74
127 C	Control	"	17.3	37.2	1.32	8.6	102.4		3.0	101.6	4.0	28.5	22.4	0.51		41	74
128	825	"	16.7	38.0	1.30	9.2	103.1		3.1	102.3	4.2	29.0	22.4	0.53		41	74
128 C	Control	"	16.6	38.4	1.28	8.7	102.8		2.7	101.3	6.0	25.5	22.8			41	74
129	824	Intensive	17.3	38.7	1.33	9.2	102.3		3.1	102.2	3.5	29.5	21.1	0.54		41	74
129 C	Control	"	16.5	38.7	1.29	8.8	103.5		3.3	101.8	4.0	25.0	22.1			41	74
130	825	"	16.9	38.5	1.29	8.8	103.2		2.9	102.2	3.2	30.0	21.0	0.52		41	74
130 C	Control	"	17.0	38.4	1.27	8.6	102.7		2.9	101.6	5.5	23.5	22.6			41	74

Very much alike.

All equal, and quality of finest pale ale malt of season.

SECTION VI. (TABLE 39.) SEASON 1930.

BARLEYS FROM NATIONAL INSTITUTE OF AGRICULTURAL BOTANY.

Control to spring sown barleys is Spratt-Archer 37, 6.

Sample No.	Variety.	Manurial Treatment.	Barley.					Malt.							Market Valuation by Sub-Committee. Shillings.	
			Moisture per cent.	1,000 corn weight (grams) dry.	Nitrogen per cent. on dry.	Malting loss per cent. on dry.	Extract from 448 lb. raw barley.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic Power Linnæus.	Cold Water Extract per cent.	Permanently soluble N. per cent. on dry.	Barley lb. per 448 lb.	Malt lb. per 336 lb.	
NORFOLK AGRICULTURAL STATION, SPROWSTON, NORWICH.																
101	35.51	Normal	19.5	34.4	1.313	9.7	98.5	2.8	101.6	3.5	33.5	19.9	0.51	45	50	
101C	S.A.	"	19.3	32.3	1.355	9.3	98.4	2.8	100.8	3.9	35.5	23.4	0.55	37	50	
102	P.A.	"	21.0	35.7	1.372	10.5	95.2	2.6	100.9	5.6	33.5	21.6	0.54	36	50	
102C	S.A.	"	19.3	31.8	1.335	9.9	96.6	2.6	99.6	5.0	33.5	24.3	0.54	37	50	
103	P.A.	Intensive	18.4	33.6	1.413	10.9	96.5	2.7	99.6	5.0	40.0	23.1	0.54	35	49	
103C	S.A.	"	18.3	31.4	1.445	10.7	96.4	2.9	99.4	5.7	32.5	24.6	0.59	36	48	

NORFOLK AGRICULTURAL STATION, SPROWSTON, NORWICH.

101	35.51	Normal	19.5	34.4	1.313	9.7	98.5	2.8	101.6	3.5	33.5	19.9	0.51		45	50
101C	S.A.	"	19.3	32.3	1.355	9.3	98.4	2.8	100.8	3.9	35.5	23.4	0.55		37	50
102	P.A.	"	21.0	35.7	1.372	10.5	95.2	2.6	100.9	5.6	33.5	21.6	0.54		36	50
102C	S.A.	"	19.3	31.8	1.335	9.9	96.6	2.6	99.6	5.0	33.5	24.3	0.54		37	50
103	P.A.	Intensive	18.4	33.6	1.413	10.9	96.5	2.7	99.6	5.0	40.0	23.1	0.54		35	49
103C	S.A.	"	18.3	31.4	1.445	10.7	96.4	2.9	99.4	5.7	32.5	24.6	0.59		36	48

NATIONAL INSTITUTE OF AGRICULTURAL BOTANY, CAMBRIDGE.

104	35.51	Normal	13.2	37.8	1.496	9.5	105.3	2.9	100.6	2.8	46.0	17.2	0.50		50	57
104C	S.A.	"	12.6	36.6	1.510	9.8	105.4	2.7	100.3	2.8	40.5	18.4	0.50		48	57
105	P.A.	"	13.9	38.5	1.561	9.3	103.7	2.8	99.6	3.1	46.5	18.7	0.52		49	57
105C	S.A.	"	13.3	34.7	1.538	9.2	104.3	2.7	99.3	3.0	43.5	18.5	0.52		48	57
106	P.A.	"	13.0	38.5	1.621	10.0	103.7	2.7	99.3	3.8	48.5	18.7	0.55		48	57
106C	S.A.	"	12.8	35.0	1.627	9.7	104.1	2.7	99.1	3.0	47.5	19.4	0.56		47	57

EAST ANGLIAN INSTITUTE OF AGRICULTURE, GOOD EASTER, NEAR CHELMSFORD.

107	35.51	Normal	15.3	35.0	1.377	10.7	102.3	2.9	101.5	3.3	34.5	19.3	0.52		47	58
107C	S.A.	"	14.9	35.1	1.311	10.4	103.9	2.9	102.2	3.8	30.5	21.0	0.52		47	58
108	P.A.	"	14.4	36.8	1.404	11.7	102.3	3.0	101.5	4.2	38.0	20.7	0.55		42	58
108C	S.A.	"	14.6	35.0	1.323	11.1	103.5	3.0	102.3	4.5	31.0	22.5	0.54		43	58
109	P.A.	Intensive	14.5	36.7	1.503	12.1	101.2	3.0	101.0	4.1	45.5	21.4	0.57		42	58
109C	S.A.	"	15.2	33.8	1.329	11.4	101.9	2.8	101.7	4.5	30.5	22.2	0.55		43	58
	Autumn Sown.															
110	P.A.	—	13.9	37.6	1.389	9.9	105.3	2.6	101.9	4.1	35.5	19.8	0.52		45	60
110C	B 244	—	14.0	31.6	1.370	9.7	102.0	2.6	98.7	2.6	38.5	16.7	0.41		38	56
111	Carter's Six-rowed															
	Winter	—	13.4	40.2	1.424	10.5	102.9	3.2	99.6	4.3	39.5	20.6	0.50		Not a malting barley.	
111C	B 244	—	13.6	30.4	1.354	10.3	101.4	3.0	98.1	2.6	40.5	16.8	0.42		38	56

LORD WANDSWORTH AGRICULTURAL COLLEGE, LONG SUTTON, NEAR BASINGSTOKE.

112	35.51	Normal	15.3	40.8	1.462	9.5	104.0	3.0	101.8	3.2	40.0	20.7	0.51		48	57
112C	S.A.	"	14.7	39.6	1.359	9.4	105.3	3.1	102.3	3.2	32.0	19.5	0.50		48	57
113	P.A.	"	15.6	42.0	1.373	10.9	102.0	3.3	102.0	3.3	39.0	19.4	0.50		49	57
113C	S.A.	"	13.9	40.0	1.385	10.4	104.8	2.8	102.0	3.8	33.0	20.4	0.50		48	56
114	P.A.	Intensive	14.2	43.6	1.364	10.8	104.3	3.2	102.3	3.3	40.0	19.0	0.49		49	57
114C	S.A.	"	13.4	40.3	1.378	10.5	105.2	3.0	101.9	3.2	35.0	19.9	0.51		48	56
	Autumn Sown.															
115	P.A.	—	14.2	38.6	1.452	10.7	103.2	2.7	101.0	3.2	40.0	20.9	0.48		53	70
115C	B 244	—	15.1	30.2	1.342	10.2	98.9	3.0	97.4	2.5	36.5	17.7	0.41		38	56
116	Carter's Six-rowed															
	Winter.	—	15.0	40.0	1.542	8.8	99.8	3.1	96.5	3.3	43.0	19.1	0.46	(18) grinding.		
116C	B 244	—	15.1	30.4	1.377	9.7	99.6	3.0	97.5	2.5	35.0	17.0	0.39		38	56

SECTION VI. (TABLE 39.) SEASON 1930. N.I.B.A. BARLEYS.

Sample No.	Variety.	Manurial Treatment.	Barley.					Malt.					Market Valuation by Subcommittee, Shillings.	
			Moisture per cent.	1,000 corn weight (grams) dry.	Nitrogen per cent. on dry.	Mating loss per cent. on dry.	Extract from 448 lb. raw barley.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic Power, Lintner°.	Cold water extract per cent.	Permanently soluble N., per cent. on dry.	Barley per 448 lb.

SOMERSET FARM INSTITUTE, CANNINGTON, NEAR BRIDGEWATER.

117	35/51	Normal	18.2	39.4	1.329	7.8	101.8	3.2	101.2	3.0	33.5	18.1	0.46	54	67		
117C	S.A.	"	18.3	38.8	1.274	7.3	101.7	3.2	100.7	3.0	28.0	18.9	0.44	54	67		
118	P.A.	"	18.0	41.8	1.372	9.2	101.6	3.2	100.9	4.0	35.0	20.7	0.50	54	67		
118C	S.A.	"	18.2	36.6	1.234	7.6	102.4	3.2	101.6	3.1	28.5	19.4	0.46	54	67		
119	P.A.	Intensive	17.2	41.0	1.334	9.9	101.0	3.0	101.5	4.8	29.0	21.4	0.61	53	67		
119C	S.A.	"	17.0	36.6	1.282	8.9	101.9	3.1	101.1	4.0	27.0	20.6	0.47	53	67		

Valuers' Note: Barleys 35/51 and Pl. Archer slightly better than Sp. Archer, though priced the same.
All remarked on as beautiful barleys.

HARPER ADAMS AGRICULTURAL COLLEGE, NEWPORT, SALOP.

120	35.51	Normal	17.3	37.9	1.570	9.1	100.3	3.1	100.1	3.9	45.5	19.3	0.55	26	49		
120C	S.A.	"	18.2	36.3	1.505	8.8	99.9	3.0	100.3	4.0	45.0	21.6	0.55	26	49		
121	P.A.	"	18.4	36.8	1.458	9.2	99.4	3.0	100.6	4.2	43.5	20.2	0.62	26	49		
121C	S.A.	"	18.5	36.5	1.441	8.0	100.5	3.0	100.5	3.7	43.0	20.2	0.52	26	49		
122	P.A.	Intensive	17.8	39.2	1.426	9.9	99.8	3.0	101.1	4.5	42.0	24.7	0.54	26	49		
122C	S.A.	"	18.0	36.8	1.501	8.7	100.4	3.1	100.6	4.2	42.0	21.1	0.54	26	49		

VALUERS' NOTES, 1930 Barleys:

Barleys. CARTER'S SIX-ROWED WINTER a grinding barley only.

B 244 not a barley for malting for sale on account of small size and screening loss.

Malts. 35/51 could generally be picked out as being a shade brighter and yellower in appearance than the other two-rowed malts.

B 244. Casual examination hardly distinguishes this from two-rowed malts. It has none of the husky characteristics of foreign six-rowed malts, and would not be expected to have the drainage value of the latter. It contains, however, a proportion of small thin and uneven sized corns which reduce value.

CARTER'S SIX-ROWED WINTER. Useless for malting.

SECTION VI. (TABLE 40.) SEASON 1931. N.I.A.B. BARLEYS.

Sample No.	Variety.	Manurial Treatment.	Barley.					Malt.					Market valuation by Sub-Committee. Shillings.			
			Moisture per cent.	1,000 corn weight (grams) dry.	Nitrogen per cent. on dry.	Milling loss per cent. on dry.	Extract calculated to 448 lb. raw.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic Power. Lintner°.	Cold Water Extract per cent.	Permanently soluble N., per cent. on dry.	Barley per 448 lb.	Malt per 336 lb.	
EAST ANGLIAN INSTITUTE OF AGRICULTURE, GOOD EASTER, NEAR CHELMSFORD.																
121	B.35/51	—	19.0	39.4	1.57	9.9	98.1	2.8	100.9	6.0	47.5	24.1	0.60	40	55	
122	Spratt-Archer	—	19.3	39.3	1.48	8.1	100.7	2.9	101.8	6.0	38.0	25.6	—	40	55	
123	Spratt-Archer	Normal	19.5	37.6	1.38	8.5	99.7	2.8	101.5	6.5	29.0	27.3	—	40	55	
124	Plumage-Archer	..	19.6	40.8	1.45	9.3	99.9	2.4	102.7	7.5	41.0	26.8	0.59	40	55	
125	Spratt-Archer	Intensive	19.7	36.5	1.53	8.8	98.1	2.3	100.4	8.0	39.0	25.7	—	40	55	
126	Plumage-Archer	..	19.8	39.1	1.38	9.7	98.9	2.0	102.4	8.5	32.0	28.1	—	40	55	
Samples from Observation Plots.																
127	Chevallier	—	18.1	41.9	1.78	11.5	96.3	2.1	99.7	8.0	47.0	24.1	0.68	40	55	
128	Goldthorpe	—	18.1	46.4	1.82	12.0	93.3	2.9	97.6	7.5	51.0	25.9	0.72	32	53	
129	Plumage	—	17.9	46.9	1.60	10.8	98.2	2.4	100.8	7.7	44.0	25.1	0.66	34	55	
130	Standwell	—	17.7	47.0	1.84	13.5	93.6	2.8	98.6	12.0	53.5	29.1	0.80	31	53	
The values questioned the purity of the seed of Chevallier, though the sample was better than that from Cambridge.																
LORD WANDSWORTH AGRICULTURAL COLLEGE, LONG SUTTON, NEAR BASINGSTOKE, HANTS.																
131	B.35/51	—	20.2	33.0	1.50	8.7	98.5	2.3	101.5	6.5	40.5	24.2	0.60	40	64	
132	Spratt-Archer	—	20.7	32.8	1.42	8.4	98.5	2.4	101.8	7.0	37.0	25.0	—	42	64	
133	Spratt-Archer	Normal	19.8	33.2	1.34	8.6	99.6	2.4	102.0	7.5	30.0	26.9	—	40	64	
134	Plumage-Archer	..	20.5	38.0	1.47	9.4	98.3	2.8	102.5	8.2	38.0	24.9	0.60	38	63	
135	Spratt-Archer	Intensive	19.7	32.5	1.50	8.4	99.9	2.3	101.9	8.0	30.0	26.9	—	40	64	
136	Plumage-Archer	..	20.5	33.4	1.48	9.4	97.2	2.3	101.2	8.5	37.5	25.4	—	37	54	
Samples from Observation Plots.																
137	Chevallier	—	18.6	35.3	1.48	8.9	100.3	2.9	101.5	7.5	24.5	25.3	0.58	45	64	
138	Goldthorpe	—	18.5	38.6	1.37	8.3	102.0	2.9	102.3	7.5	30.0	25.6	0.58	45	60	
139	Plumage	—	18.7	37.2	1.28	7.7	103.5	2.9	103.6	7.8	27.5	25.4	0.55	45	62	
140	Standwell	—	19.0	40.7	1.58	10.2	100.3	2.8	103.4	14.5	40.0	28.3	0.72	40	55	
Chevallier in each more typical and apparently pure.										Malts 138, 139, 140 skinned rather badly.						
SOMERSET FARM INSTITUTE, CANNINGTON, NEAR BRIDGEWATER.																
141	B.35 51	—	19.3	37.6	1.39	8.5	101.1	2.7	102.6	7.0	33.0	23.9	0.56	55	72	
142	Spratt-Archer	—	19.8	37.0	1.38	9.0	98.9		101.6	6.0	29.0	25.1	—	52	72	
143	Spratt-Archer	Normal	19.2	37.0	1.34	7.5	101.7	2.8	102.2	7.0	27.0	26.7	—	53	66	
144	Plumage-Archer	..	19.3	41.7	1.34	8.8	101.2	2.3	103.1	8.3	29.0	25.4	0.56	52	66	
143 had better skin than 145; 144 better bloom than 146.										Malt 144 slightly preferred to 143.						
145	Spratt-Archer	Intensive	19.5	37.0	1.38	8.0	100.3	3.1	101.5	6.2	28.0	26.0	—	52	72	
146	Plumage-Archer	..	18.9	40.8	1.38	9.0	100.7	2.8	102.5	8.2	29.0	26.8	—	53	66	
145 was a trifle coarse; 146 a trifle better quality than 144																
Samples from Observation Plots.																
147	Chevallier	—	19.4	37.6	1.41	8.8	100.9	3.0	102.9	7.2	30.5	23.7	0.58	56	73	
148	Goldthorpe	—	20.6	41.3	1.40	9.3	97.4	2.5	101.5	7.8	28.5	23.1	0.57	52	75	
149	Plumage	—	19.6	41.5	1.34	7.25	102.6	2.3	103.2	8.0	31.0	23.6	0.56	53	75	
150	Standwell	—	20.1	54.6	1.92	8.6	97.5	3.1	100.1	5.3	61.0	22.8	0.72	25	37	
147 most typical and best barley of Chevalliers.										Malt 149, wonderful bloom.						
150 unripe, very steely.																
HARPER ADAMS AGRICULTURAL COLLEGE, NEWPORT, SALOP.																
151	B.35.51	—	21.7	35.4	1.44	10.1	93.9	2.4	100.3	9.3	21.5	21.7	—	28	Un-saleable	
152	Spratt-Archer	—	21.7	36.5	1.47	8.8		2.4	100.5	9.0	23.0	22.7	—	28		
153	Spratt-Archer	Normal	21.5	36.1	1.52	8.7	95.4	3.3	100.5	7.7	24.5	23.5	—	28	weather	
154	Plumage-Archer	..	21.9	40.5	1.43	9.4	96.1	2.6	100.0	10.0	21.0	21.9	—	28		
155	Spratt-Archer	Intensive	22.0	36.5	1.41	10.0	94.8	3.0	101.3	7.0	24.5	23.1	—	28	aprotected	
156	Plumage-Archer	..	21.3	40.6	1.37	9.5	97.3	2.8	102.6	10.0	20.0	22.1	—	28		

SECTION VII. MANURIAL AND DRILLING EXPERIMENTS.

NORFOLK AGRICULTURAL STATION, SPROWSTON, NORWICH.

Light Loam—Overlying Gravel.

TABLE 41. SEASONS 1925 TO 1930.

Sample No.	Manurial Treatment.	Barley.						Malt.					Market valuation by Sub-Committee. Shillings.	
		Moisture per cent.	1,000 corn weight (grams) dry.	Nitrogen per cent. on dry.	Malting loss per cent. on dry.	Extract calculated to 448 lb. raw.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic power. Lintner.	Cold Water extract per cent.	Barley 448 lb. Nov., 1925.	Malt 336 lb. Dec., 1925.	
SEASON 1925.														
A. Plumage-Archer Barley.														
120	No manure	17.16	34.1	1.537	10.9	95.0	2.66	96.5	11.5	20.0	23.5	50	70	
121	1½ cwt. S/Am.	17.70	35.0	1.645	11.8	92.5	2.64	95.6	13.0	22.0	23.1	45	68	
122	3 cwt. S/Am.	17.44	33.8	1.917	11.9	89.2	2.28	92.3	19.5	26.5	23.5	45	67	
B. New Cross Barley.														
123	No manure	17.10	34.9	1.489	9.8	98.3	2.48	98.7	6.0	21.5	20.8	55	70	
124	1½ cwt. S/Am.	17.16	35.1	1.647	11.1	94.0	2.48	95.8	8.5	23.0	21.6	50	69	
125	3 cwt. S/Am.	17.52	34.9	1.783	10.8	92.8	2.80	94.6	9.5	24.5	22.4	50	67	
SEASON 1926.														
Sample No.	Manurial Treatment.	Barley.						Malt.					Market valuation by Sub-Committee. Shillings.	
		Moisture per cent.	1,000 corn weight (grams) dry.	Nitrogen per cent. on dry.	Malting loss per cent. on dry.	Extract calculated to 448 lb. raw.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic power. Lintner.	Cold Water extract per cent.	Barley 448 lb. Nov., 1926.	Malt 336 lb. Dec., 1926.	
Balanced manures, with Phosphate and Potash. Plumage-Archer.														
120	Control	16.60	33.9	1.573	—	—	3.4	98.2	5.8	46.0	24.1	38	54	
121	½ cwt. S/Am.	16.54	33.9	1.516	—	—	3.5	98.6	5.0	46.0	23.9	38	55	
122	1 cwt. S/Am.	16.36	33.0	1.511	—	—	3.1	97.8	6.0	49.3	23.3	38	54	
123	1½ cwt. S/Am.	16.38	32.5	1.508	—	—	2.9	98.2	6.8	48.6	25.4	37	54	
124	3 cwt. S/Am.	16.36	31.5	1.754	—	—	3.4	96.0	5.7	51.3	24.5	37	52D	
Unbalanced. S/Am. only.														
125	½ cwt. S/Am.	16.82	34.6	1.557	—	—	3.3	97.5	5.3	46.6	23.3	38	55D	
126	1 cwt. S/Am.	16.20	34.8	1.633	—	—	3.3	97.3	7.2	46.0	24.3	38	54	
127	1½ cwt. S/Am.	16.60	34.2	1.644	—	—	3.3	97.4	6.8	50.0	23.8	37	54	
128	3 cwt. S/Am.	16.20	32.8	1.768	—	—	3.3	95.3	4.5	66.6	23.3	37	53	
Plumage-Archer.														
129	Spring sown	17.04	33.2	1.632	12.4	92.9	3.1	96.0	8.0	37.0	27.1	38	53	
130	Autumn sown	16.94	39.2	1.421	10.0	99.7	3.2	100.1	5.8	35.1	22.9	62D	67D	
Balanced. New Cross.														
131	Control	16.40	31.6	1.546	9.8	97.6	2.9	97.2	6.5	37.4	24.0	39	55	
132	½ cwt. S/Am.	17.02	31.9	1.483	9.9	96.9	2.9	97.2	5.0	35.3	23.5	39	54	
133	1 cwt. S/Am.	16.40	32.2	1.515	10.9	97.0	2.8	97.7	7.0	36.0	24.7	39	56D	
134	1½ cwt. S/Am.	16.30	31.9	1.546	10.7	97.3	3.1	97.6	7.0	38.5	24.6	39	55D	
135	3 cwt. S/Am.	16.42	31.7	1.639	11.0	95.6	2.8	96.4	6.8	46.0	24.0	39	54D	
Unbalanced.														
136	½ cwt. S/Am.	16.90	33.2	1.471	9.9	98.7	3.1	98.9	5.0	32.8	22.9	39	55	
137	1 cwt. S/Am.	16.58	32.3	1.540	10.1	98.1	2.9	97.9	5.0	35.4	23.5	39	55	
138	1½ cwt. S/Am.	16.40	31.7	1.622	10.7	96.9	3.0	97.4	6.8	36.0	25.5	39	54D	
139	3 cwt. S/Am.	16.50	30.9	1.834	11.4	93.3	3.0	94.9	5.0	47.0	24.0	37	53	

SECTION VII. (TABLE 41).

MISCELLANEOUS EXPERIMENTS, NORFOLK AGRICULTURAL STATION.

Sample No.	Treatment.	Barley.						Malt.						Market valuation by Sub-Committee. Shillings.	
		Moisture per cent.	1,000 corn weight (grams) dry.	Nitrogen per cent. on dry.	Making loss per cent. on dry.	Extract calculated to 448 lb. raw.	Moisture per cent.	Extract per 336 lb. dry.	Colour.	Diastatic Power. Lintner.	Cold Water Extract per cent.	Perm. Sol. N. per cent. on dry.	Barley per 448 lb.	Malt per 336 lb.	

SEASON 1927. *Plumage-Archer.*

120	Nil ..	18.52	38 0	1.38	9 0	101 2	3 40	102 3	4 5	45.0	21 5	—	59	80
121	$\frac{1}{2}$ cwt S/A	18.72	38.6	1.28	8 1	103.1	3 42	103 5	3 5	45.0	22.4	—	68	82
122	1cwt S/A	18.84	39 0	1.27	8 2	103.0	3 36	103.6	4 0	40 0	22 2	—	70	82
123	$\frac{1}{2}$ cwt S/A	18.76	37.7	1.30	8 0	102.9	3.34	103 3	3 5	42 0	21.6	—	67	82
As above after sheep.														
120S	Nil ..	19.32	36 4	1.53	8 7	89 0	3 28	100 8	3 8	54 5	21.1	—	51	77
121S	$\frac{1}{2}$ cwt S/A	19.26	37.8	1.45	8.7	100 1	3.16	101.9	3.8	52 0	20 9	—	52	78
122S	1cwt S/A	19.26	38.4	1.46	8 1	100.5	3.22	101.6	4.0	47 5	21.4	—	57	78

SEASON 1928.

Drilling Experiment.

38	7" apart													
39	2½ bush p.a.	15.9	39.1	1.53	10 5	101 0	3 36	101.1	2 7	44 5	23 4	—	45	60
	3½" apart													
40	2½ bush p.a.	16 5	38.2	1.46	10 4	101.3	3.62	101.6	2.5	45.5	24 3	—	45	60
	3½" apart													
	4 bush p.a.	16 3	36.0	1.45	11 7	100.1	3 42	101.6	2 7	41 0	24 4	—	47	60

Manurial Trials after sheep.

41	$\frac{1}{2}$ N ..	16.1	33 4	1.59	12.1	97 7	3.46	99.4	3 2	45.5	26 3	—	44	60
42	$\frac{1}{2}$ KsP $\frac{1}{2}$ N	16.3	34 2	1.49	11.8	98.7	3.08	100.2	3 5	42.0	26.5	0.55	44	59
43	O ..	16.8	33 4	1.47	11.7	97 8	3.34	99.8	2 8	42.0	27 0	—	44	59
44	N.K.sP	15.8	30 2	1.79	12.8	93.4	3.30	95.5	3 2	57.0	26.0	0.65	38	55
45	NP ..	15.7	32 7	1.66	12.3	95.9	3.30	97.1	3 2	48.5	26.6	—	43	58
46	NK ..	15.8	32 9	1.68	13 0	95.4	3.04	97 8	3.7	52 0	26 8	0.62	43	57
47	KP ..	15.9	33 2	1.52	10.3	99 1	3.14	99.7	3.0	48.0	26 6	0.56	43	61
47N	N only	16 5	31.3	1.60	11 4	96 9	3 18	98.3	2.8	57 5	26 0	—	40	59
48	Ks ..	16 0	34.0	1.40	11.5	100 0	3.74	100.9	2.8	41.0	25 4	—	45	59
48M	Km ..	16 0	35.0	1.55	11.6	99.8	3 34	100.8	2.8	49.0	25 0	—	44	59
49	P ..	16 1	32 9	1.48	11 6	99 4	3.30	100.4	3.0	45 5	25.6	—	43	59

O = No Manure.
N = 1 cwt. Sulphate of Ammonia, per acre.
P = 3 cwt. Superphosphate " "
K = $\frac{1}{2}$ cwt. Sulphate of Potash " "
Ks = 1 cwt. " " " "
Km = 1 cwt. Muriate " " " "

SECTION VII. (TABLE 41). NORFOLK AG. STN. EXPERIMENTS

SEASON 1929.

Sample No.	Treatment. (See above.)	Moisture per cent.	1,000 corn weight (grams) dry.	Nitrogen per cent. on dry.	Market Valua- tion by Sub- Committee. Shillings per 448 lb.
66	O	13.6	37.6	1.37	47
67	N	13.9	39.8	1.51	47
68	K P	14.1	39.7	1.39	47
69	N K	14.3	39.8	1.46	47
70	N P	14.3	40.9	1.53	47
71	N P K	14.4	39.6	1.46	47
72	1/2 N P K	14.3	38.4	1.46	47
73	1/2 N	14.4	39.0	1.40	47
74	P	14.1	37.2	1.20	47
75	K	13.6	37.2	1.28	47
76	K (muriate)	14.0	39.2	1.32	47
77	2 1/2 bushels, close drilling ..	13.9	36.4	1.35	48
78	2 1/2 .., ordinary drilling ..	13.8	36.2	1.10	48
79	4 .., Close ..	14.2	36.2	1.34	48
80	2 1/2 .., ordinary ..	14.0	39.3	1.33	48
81	Sugar beet tops ploughed in ..	14.0	37.4	1.31	48
82	.. .., .. carted off ..	14.0	36.9	1.19	48

Not malted

SEASON 1930.

Sample No.	Manurial Treatment, cwt per acre	Moisture, per cent	1,000 corn weight (grams) dry.	Nitrogen per cent. on dry.	Market Valua- tion by Sub- Committee. Shillings, per 448 lb.
123	1 Muriate of Potash ..	8.66	35.4	1.40	26
124	2 S/A., 3 Super, 1 S/Pot.	8.44	33.9	1.48	26
125	No Manure ..	8.40	34.7	1.40	26
126	1 S/A., 1 S/Pot. ..	8.38	31.9	1.52	26
127	1 S/A. ..	8.32	34.0	1.47	26
128	1 S/Pot. ..	8.90	34.0	1.46	26
129	1 S/A., 3 Super, 1 S/Pot.	8.30	33.9	1.47	25
130	1 S/A., 3 Super. ..	8.88	33.1	1.48	26
131	3 Super. ..	9.66	34.4	1.47	26
132	3 Super., 1 S/Pot. ..	9.00	34.1	1.44	26
133	1/2 S/A. ..	8.42	33.8	1.46	26
134	Sugar Beet Tops ploughed in ..	8.58	34.3	1.46	26
135	.. .., .. carted off ..	8.68	34.8	1.34	26
136	Close Drilling, 2 1/2 bushel/acre ..	8.98	35.2	1.44	26
137	Ordinary .., 2 1/2 .. / ..	9.12	34.4	1.44	26
138	Close .., 4 .. / ..	9.14	34.4	1.44	26
139	Ordinary .., 4 .. / ..	8.28	35.6	1.46	26

Valuer's Note: All very poor. 137 slightly better than 136.
Not malted.

THE INSTITUTE OF BREWING RESEARCH SCHEME.

FIRST REPORT ON BARLEY PROTEINS.

THE COMPOSITION AND QUANTITATIVE ESTIMATION OF BARLEY PROTEINS.

By L. R. BISHOP.

THIS section of the Barley Research work deals with the nitrogen compounds in barley and malt. The present report is an outline of the preliminary investigations on the barley nitrogen compounds and their behaviour in malting. The aim of the research is to elucidate the part played by the nitrogen compounds in brewing.

1.—ISOLATION AND COMPOSITION OF THE PROTEINS.

The work of Osborne (2) clarified the position and established the existence in barley of four proteins (three of them clearly defined individuals) together with protein decomposition products such as proteoses, etc.

They are :—

An Albumin, soluble in water (and in dilute salt solutions and alkalis).

A Globulin, soluble in salt solutions (and in alkali).

A Gliadin (Hordein) soluble in 75 per cent. alcohol (and in alkali).

A Glutelin (not purified), soluble in alkali in the absence of salts.

Subsequent work has not affected this division seriously, and the classification of the individuals may be taken as fairly well established.

Osborne applied specific names to the albumin (leucosin) and globulin (edestin) believing them, on the basis of elementary analysis, to be identical with corresponding proteins in other plants. Analysis shows that the relative amounts of the constituent amino-acids in the barley proteins probably differ from those of other plants, *e.g.*, Edestin of barley differs from that of hemp seed and leucosin of wheat from that of barley. Hence these specific names will not be employed and the proteins will be referred to as barley albumin and globulin.

Osborne (2) and some later workers characterised the proteins by their elementary composition, *i.e.*, by the percentages of carbon, nitrogen, hydrogen and oxygen. These vary so little between different proteins that very accurate estimation is necessary and even then elementary composition cannot be regarded as a good test of individ-

uality. Methods have since been evolved for characterising the individuality of proteins by the amounts of various amino-acids to groups of amino-acids which they contain. Some of these methods have been used in the present investigation.

The results obtained by various workers on barley proteins by these methods are summarised below.

Hordein.—Of the four proteins of barley this is the easiest to prepare pure, and hence has been investigated more than the others. A number of analyses are given by previous workers. Osborne and Harris (3) obtained the following Hausmann numbers :—

Amide N	23.3	per cent.
Humun N	1.3	per cent.
Basic N	4.5	per cent.
Non-Basic N	70.0	per cent.

Osborne and Clapp (4) and also Kleinschmidt (5) subjected hordein to an analysis by the ester method, with the following results, which show the order of agreement of the analyses of various authors :—

	Osborne and Clapp (1907).	Kleinschmidt (1907).
Glycocoll	0.00	0.00
Alanine	0.43	1.34
Valine	0.13	1.40
Leucine	5.67	7.00
Proline	13.73	5.88
Phenylalanine ..	5.03	5.48
Aspartic Acid ..	—	1.32
Glutamic Acid ..	36.35 (43.20 later)	41.32
Serine	—	0.10
Cystine	doubtful	—
Tyrosine	1.67	4.00
Oxyproline	doubtful	—
Arginine	2.16	3.14
Histidine	1.28	0.51
Lysine	0.00	0.00
Ammonia	4.87	4.34
Total	71.32	75.83

Luers (6) and Hoffman and Gortner (7) have published Van Slyke analyses ;—

		Luers.	Hoffman and Gortner
Amide N	.. ..	23.00%	23.38%
Humin N	.. ..	1.70%	1.44%
Basic	Cystine N..	1.58%	1.38%
	Arginine N	5.00%	6.22%
	Histidine N	0.93%	10.36X%
	Lysine N..	0.18%	3.02%
Non-Basic	Amino N of Filtrate	53.85%	50.41%
	Non-amino N of Filtrate	12.40%	3.65X%

These may be summarised for comparison with Osborne and Harris's results above as :

		Luers.	Hoffman and Gortner.
Amide N	... ..	23.00%	23.38%
Humin N	... ..	1.70%	1.44%
Basic N	... ..	7.69%	20.98%
Non-basic N	... ..	66.34%	54.06%

Proline tends to precipitate as phosphotungstate and appear in the analysis as histidine instead of appearing as non-amino nitrogen. This probably explains the results of Hoffman and Gortner, as their histidine and non-protein nitrogen values differ widely from those suggested by other methods. I am trying to overcome this difficulty.

The following figures have been published on the basis of colorimetric determinations :—

Tryptophane.	Cystine.	
0.45	1.47	Jones, Gersdorff and Mouller (8).
1.06	1.55	

Albumin.—I have prepared this in a fairly pure state and analysed it by the Van Slyke method. The results compare tolerably well with those of Luers and Landauer (9).

TABLE I.

	Luers & Landauer.	Author.
Amide N	.. .. 9.40%	9.29%
Humin N	.. .. 1.10%	2.29%
Cystine N	.. .. 1.47%	—
Arginine N	.. .. 11.64%	18.31%
Histidine N	.. .. 4.48%	0.20%
Lysine N	.. .. 8.44%	9.67%
Amino N of Filtrate	.. .. 60.44%	58.93%
Non-amino N of the Filtrate	.. .. 2.67%	2.54%

Globulin.—This has been studied, but I am not yet satisfied with the purity of the specimens I have prepared and analysed. No details of its composition have been published apart from its elementary composition.

It is not considered that present methods for separating these proteins (albumin and globulin) are satisfactory, and I am trying to improve the methods with a view to obtaining data which are less approximate.

Glutelin.—Osborne was unable to obtain this pure. A method, which is discussed later (page 109), has recently been worked out.

Jones and Gersdorff (10) and (11) have examined the proteins of wheat bran, and consider them different in composition from those of the endosperm. If this is confirmed then a similar difference might occur between the proteins of barley endosperm and husk. However, as Jones and Gersdorff attempted to obtain their proteins quantitatively as well as pure, the purity is open to doubt.

II.—QUANTITATIVE ESTIMATION OF THE PROTEINS.

For purposes of quantitative estimation the criterion of solubility in specified solvents seems to give the sharpest separation and it is on this basis that most methods for estimating cereal proteins have been worked out.

Schjerning (12) attempted the separation by precipitation with heavy metal salts. This process involves adsorption and salt formation, and the precipitations are usually balanced reactions. The evidence seems to suggest that his precipitates are not definite separations of individual proteins. His claim that albumin I. and II. correspond to Osborne's globulin and albumin is based on a single experiment (13), in which he obtained approximately equal amounts of nitrogen in his precipitates, and in these proteins estimated in a manner somewhat similar to Osborne's method. Schjerning's immense masses of data (*Compt. rend. Trav. Lab. Carlsberg*) are consequently of questionable value.

In the following consideration of methods, experience with wheat will be drawn upon, since the problem of the estimation of wheat proteins has received a good deal of attention recently, and the problems are very similar; so that this work helps to throw light on the methods to be employed in barley.

Various papers on wheat protein estimation have been summarised by Bailey and Blish (14) and Sharp and Herrington (15).

It becomes clear from these summaries, that, as might be expected, the characteristic solvent for a particular protein does not extract that protein alone. For instance, Osborne (2) realised quite clearly that alcohol extracts other substances in addition to the alcohol-soluble protein, so that even in most of his qualitative preparations he extracted the barley or wheat flour with sodium chloride solution before the alcohol extraction. Despite this, nearly all the workers since that time (1895), in attempting even quantitative estimations of alcohol-soluble proteins of wheat and barley, have extracted the flour directly with alcohol. The fact that H. T. Brown (16) used alcoholic extraction as a method of separating amides, amino-acids and "unclassified nitrogen" from barley, makes it clear that the alcohol-soluble protein is not the only nitrogen compound in barley which dissolves in alcohol.

The albumin and proteoses, amino-acids, etc., cannot be extracted by water before extracting the globulin by salt solution, since barley contains free salts such as phosphates which dissolve some of the globulin.

The best method is to extract first with salt solution and then with 70 per cent. (by volume) alcohol. However, the alcohol-soluble protein is soluble to a small extent in water and salt solutions. Osborne investigated this and states (2) "It is the opinion of the writer that the hordein of barley is decidedly less soluble in water than the gliadin of wheat." Consequently, the problem of sharp separation of proteins in barley appears to be easier than with wheat.

Bailey and Blish (14) attempted to ascertain the solubility of gliadin in their salt solution extracts of wheat by an ingenious method, which is of no value in this case; nevertheless, as this method is of value in the alcohol extract it will be explained in detail.

It depends on the fact that gliadin of wheat has a very high percentage of amide nitrogen (25.52 per cent. is quoted as the best determination), while the amide nitrogen of wheat albumin is 6.8 per cent. and of the globulin 7.7 per cent. Amide nitrogen determinations of different workers on the same protein in the Van Slyke process agree much more accurately than do any of the

other figures, so this appears to be the most accurate character which can be determined chemically. Bailey and Blish argued that the ratio of amide to total nitrogen (ammonia percentage) of the salt solution should be that of the mean of the percentages in albumin and globulin. This mean was adjusted to allow for the relative amounts of albumin and globulin. Higher percentages would then indicate the amount of gliadin. This neglects the fact that approximately half of the salt extract consists of proteoses, amino-acids and other nitrogenous compounds, and consequently the method is of no value in this case.

In attempting to estimate the solubility of hordein in salt solutions, I used two methods, both of which indicated that it was low. Details are given in the following section.

After the salt extraction it seems possible to extract the alcohol-soluble protein quantitatively by hot alcohol, as the only nitrogen compound present. The purity is indicated by the ammonia percentage method of Bailey and Blish which can be applied here. Bailey and Blish obtained with wheat 25.57 per cent. of ammonia in the alcohol extract after salt extraction (value quoted for pure gliadin 25.52 per cent.).

The ammonia percentage of the alcohol extract determined by myself for barley agrees closely with that for pure hordein.

	Ammonia % of Extract.	Values for pure hordein.
Barley "B"	23.3	Osborne (2) 23.3% Luers (6) 23.00%
Orwell Barley, 1925	23.2	Hoffman & Görtner (7) 23.38%

Hence the total nitrogen of the alcohol extract may be taken as a measure of the hordein present.

Undoubtedly the alcohol extracts bodies of the lecithin type, which contain some nitrogen. However the amount of these appears to be small both from the evidence above and from the fact that only small amounts of nitrogen were obtained by ether extraction of the residue of evaporated alcoholic extracts.

Sharp and Herrington (15) show that, after salt extraction, hot alcohol removes more nitrogen from wheat flour than cold, and

since Bailey and Blish (14) show this belongs almost entirely to gliadin, it follows that the hot alcohol extraction, without decreasing the purity of the product, is more efficient than cold alcohol in extracting the alcohol-soluble protein.

Glutelin by Difference.—After the removal of salt-soluble and then alcohol-soluble nitrogen the remaining nitrogen probably represents fairly pure glutelin (which has, however, been denatured by the alcohol and cannot be extracted). That this is so with wheat is indicated by the ammonia per cent. of the residue which was found by

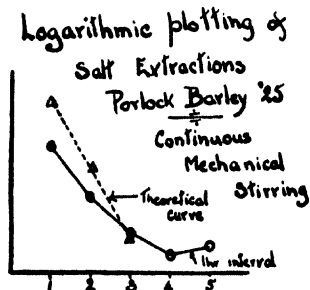
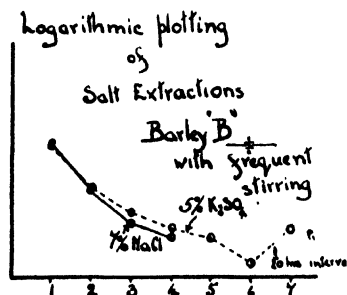
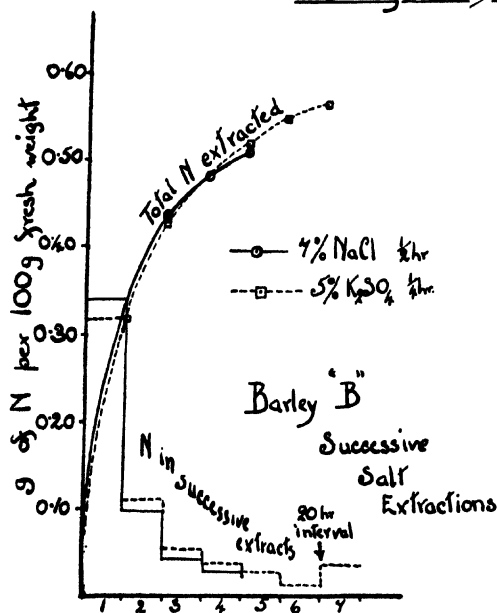
EXPERIMENTAL.

The preparation of albumin for Van Slyke analysis was made in the usual way, that is, by ammonium sulphate precipitation of sodium chloride solution extracts of barley. The precipitate was extracted with water to remove albumin and the solution then dialysed and the albumin separated by coagulation at 70°C.

The liquids were filtered at each stage and the protein washed with alcohol and ether, and dried in vacuo.

As stated above, this method is not very satisfactory, and it is hoped to improve it.

Diagram I



Bailey and Blish (14) to be 18.6 per cent., agreeing with Osborne's value of 18.8 per cent. for pure wheat glutelin.

American workers (17) have also found rough agreement between their methods for estimating wheat glutelin directly and the estimation by difference.

Similar agreement for amounts of glutelin in barley estimated by direct and indirect methods is shown below. (Diagram V.)

SALT EXTRACTION.

The results of the successive salt extractions of barley are given in Diagram I.

Note.—The percentages of nitrogen for barley "B" are calculated as percentages of the fresh weight of the sweated barley. The nitrogen percentages of all other barleys are calculated on dry matter.

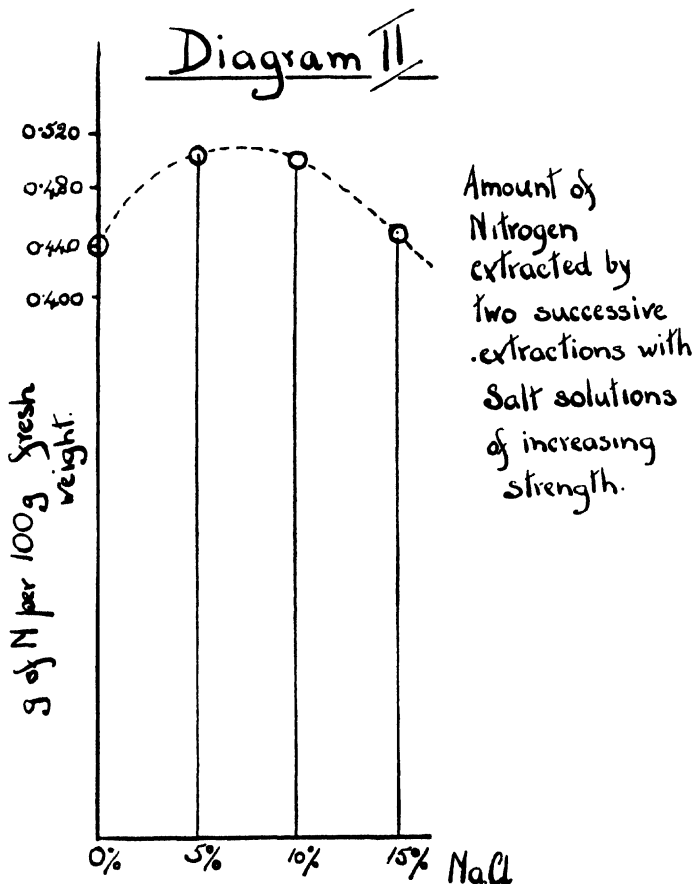
The residual solubility of nitrogen is low compared with the total amount extracted.

This solubility is due to residual albumin and globulin, to proteolysis, and to solubility of hordein and glutelin. Hence none of these factors appears to interfere seriously. The extra amount obtained by bacterial action, etc., after 20 hours is not large.

For the direct estimation of hordein solubility, preparations of hordein were made from barley previously extracted by salt solution. The hordein was precipitated in a finely divided condition and washed on the centrifuge with water to remove alcohol.

The solubilities were as follows :—

	Grms. Hordein N per 100 cc. of solution.	Amount of Hordein N which would be dissolved in 5 extractions of 70cc.
Water ..	0.0030	0.010
1% NaCl ..	0.0030	0.010
8% NaCl ..	0.0024	0.008
16% NaCl ..	0.0016	0.006
0.15% K ₂ SO ₄	0.0023	0.008
5.0% K ₂ SO ₄	0.0024	0.008



Equal amounts of hordein were added to the solutions and left to stand in the presence of toluene for 20 hours with occasional stirring. The amount of nitrogen in a known volume of the filtered solution was determined by Kjeldahl.

The amount dissolved by 350 cc. of 5 per cent. K₂SO₄ (0.008) is equivalent to 3 per cent. of the hordein nitrogen or low nitrogen barleys, and 1 per cent. on high nitrogen barleys.

Determinations of the amount extracted

by two successive extractions showed that the maximum amount of nitrogen was extracted by sodium chloride between 5 per cent. and 10 per cent. strength.

5 per cent. potassium sulphate extracted about the same amount of nitrogen as 7 per cent. sodium chloride (see Diagram I.). Hence 5 per cent. potassium sulphate was adopted as a standard, for convenience in the subsequent Kjeldahl process.

The salt extracts were too gummy to filter, and it was found necessary to centrifuge them. Even after centrifuging, filtration was very slow and the clogged filter probably acted as an ultra-filter, thus retaining proteins in true solution. Consequently the salt and alcohol extracts were centrifuged from the barley meal and the extracts poured off from the compact mass. Under these circumstances the values for the amounts extracted will probably be rather high, due to protein matter in suspension, while in the filtered extract they will be too low.

Salt extract barley "B."		
Centrifuged extract ..	0.499 grm.	N/100 grms. of sweated barley.
" " filtered..	0.473 grm.	N/100 grms. of sweated barley.
Difference ..	0.026 grm.	5% of amount extracted.

With the amounts employed in the standardised method (70 cc. of solution to 10 g. of barley) it was found that 12 grms. of solution were retained by the barley centrifuged off at 2,500 revs. per min. Hence at least three extractions would be necessary to reduce the remaining salt-soluble nitrogen to a negligible amount. It will be seen from Diagram I. that five extractions are necessary in practice owing to the slowness of the diffusion of the proteins from the particles of barley.

Continuous shaking in a mechanical shaker was found to increase the efficiency of the extraction. This can be seen in the steeper slope of the logarithmic plottings of Porlock barley compared with those of barley "B" (Diagram I.).

The solubility appears to be affected by the fineness and evenness of grinding, so that these must be standardised. An adjustable large cone coffee mill proved more satisfactory than most mills.

The p_H of the potassium sulphate solution used was between 5 and 6. This is the

isoelectric region of hordein and glutelin at which they are most insoluble.

Fractionation of Salt Soluble Substances.

—Luers and Landauer (18) have shown that p_H 4.6 is the isoelectric point of barley albumin, and this has been adopted as the point for the best coagulation of albumin. The solutions were heated to 82°C. till coagulation was complete (20 minutes). Recently, however, it has been found that the values obtained in this way for albumin were too high, since the acidity of the sodium acetate-acetic acid buffer caused some precipitation of globulin which cannot be filtered or centrifuged off completely. Hence it would be preferable to make the estimation of albumin on water extractions of barley.

Barley "B."		
Albumin N for water extraction ..	0.073%	N/100 sweated barley.
" Albumin N " 5% salt ..	0.125%	N/100 sweated barley

The albumin precipitate is too light to centrifuge off and must be filtered off for the nitrogen estimation.

Total Protein.—The amount of nitrogen in the form of fully built up proteins can be estimated approximately by precipitation with 5 percent. trichloroacetic acid or 5 percent. salicyl sulphonic acid (sulpho-salicylic acid). The amount of nitrogen precipitated depends on the concentration of the precipitant, so that only comparative results can be obtained by using standardised conditions.

Barley "B."		
5% Trichloroacetic acid N=...	0.290%	sweated barley
3% Salicyl-sulphonic acid		
N = ...	0.250%	" "
Total nitrogen of salt solution		
N = ...	0.498%	" "

These results indicate that approximately half the nitrogen of the salt extract represents fully built up proteins.

Diagram III. shows roughly the proportions of the different nitrogen compounds in the salt extract.

Non-protein Nitrogen.—This was estimated by the method of Blish (19) as modified by Olsen and Bailey (20). The solution is made alkaline by N/10 sodium hydroxide. Two drops of phenol-phthalein solution

are added and N/10 copper sulphate is then run in until the violet colour of the solution just changes permanently to green. This ensures precipitation at a constant p_H (8.0). Proteins, proteoses, and some amino-acids are removed as copper compounds by centrifuging.

The precipitation is an equilibrium reaction depending on the amount of precipitant, as is shown by the following figures.

somewhat soluble in the salt solution in which it is precipitated.

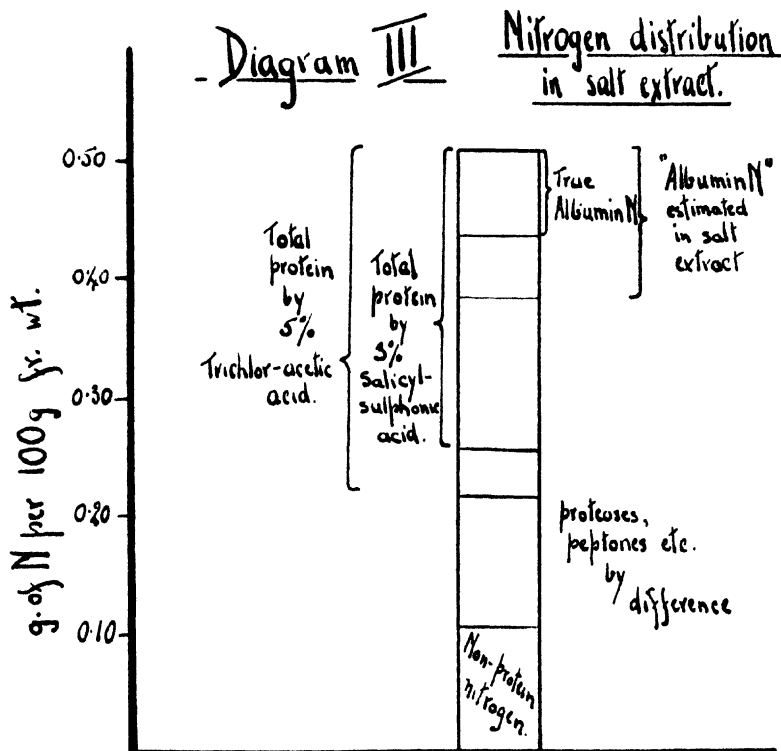
Barley 166 cc. (Archer, 1924 crop, N.I.A.B.)

The precipitate from 140 cc. salt extract was dissolved in 20 cc. N/10 alkali made to 140 cc. with 4 per cent. potassium sulphate salt solution and re-precipitated by N/10 CuSO_4 .

Nitrogen in precipitate.

Nitrogen in solution.

0.374 grm. N/100 grms. of dry barley 0.022 grm. N/100 grms. dry barley = 5.6%



Barley 167cc (Archer 1924 crop N.I.A.B.) N/100 grms. dry barley.

	Protein N	Non-protein N	Total N
140 cc. salt ex. 14 cc. N/10 NaOH ..	0.385	0.130	0.515
140 cc. salt ex. 30 cc. N/10 NaOH ..	0.425	0.078	0.503
Total nitrogen direct			0.509

The copper hydroxide-protein precipitate is

Hence comparative results only can be obtained by using standardised conditions.

The non-protein nitrogen from Blish's work (19) consists roughly of lower polypeptides, some amino-acids, asparagine and what H. T. Brown termed "unclassified nitrogen," which he showed probably contained some betaine and choline (16). By analogy with the results of Kiesel (21) on rye, compounds such as xanthine, guanine, adenine, hypoxanthine, tetramethylene-diamine, may be present.

Alcohol Extraction.—Figures of the ammonia percentage given in the previous section (page 103) indicate that the nitrogen extracted (after salt extraction) probably represents nearly pure hordein.

The alcohol-soluble protein is not very soluble in cold alcohol, when the barley has been extracted first with salt solution.

50-60 per cent. alcohol at 19° C. dissolves 0.12 per cent. of hordein nitrogen per 100 cc.=approx. 0.68/grms. hordein per 100 cc.

2,500 revs. per min. So that under the standard conditions (60 cc. of alcohol to 10 grms. of barley) three extractions would be necessary theoretically to extract nearly all the nitrogen. Successive extractions shewed that this number was sufficient in practice.

Glutelin.—Osborne (2) was unable to purify specimens of the alkali-soluble protein of barley, and pure preparations have not yet been made so that its properties are unknown.

In the quantitative experiments it has been

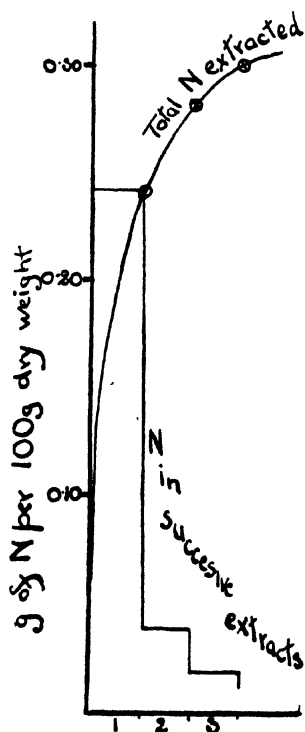
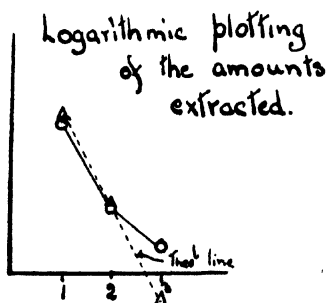


Diagram IV.
Successive Extractions
of Porlock 25 Barley
with alcohol at 82° C—
after salt extraction



So that hot alcohol must be used for the extraction. Bailey and Blish's (14) method of extracting wheat with hot alcohol under pressure, to prevent loss of solvent, appeared to be better than refluxing as being less likely to cause denaturation.

The number of extractions necessary for the complete extraction of the alcohol-soluble nitrogen under these conditions was determined. Eight grms. of alcohol are retained by 10 grms. barley centrifuged off at

estimated by difference under conditions comparable with those which when used with wheat probably give a fairly good measure of glutelin nitrogen.

Two methods which have been used or the direct estimation of wheat glutelin have been applied to barley.

(a) Blish and Stanstedt (22) dissolved all the proteins of wheat in dilute alkali, added alcohol to keep the gliadin in solution, filtered the solution clear and precipitated the

glutelin by adding acid until the isoelectric point p_H 6 was reached. The amount of nitrogen in the precipitate was then estimated. I have applied this method to barleys, using various strengths of alkali, and alcohol.

(b) Csonka and Jones (23), in order to obtain pure preparations of the glutelins, treated wheat, rice and oat flour with alkali, added alcohol, filtered and precipitated the glutelins, which are sensitive to the presence of salts, by the addition of small amounts of ammonium sulphate.

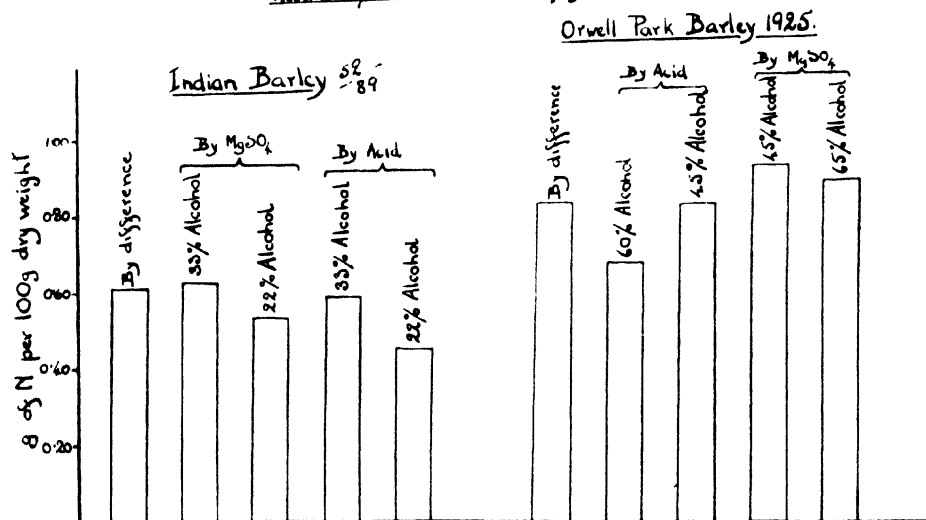
cleaned of extraneous matter and finely ground in a coffee mill, the resulting flour being well mixed to reduce sampling errors.

Moisture.—This was determined in duplicate on 5 gm. samples which were dried at 98° C. for four hours in a current of heated dry air (Siau oven).

Total nitrogen was determined in duplicate on 2 gm. samples.

Salt Extraction.—This is usually carried out with two or four samples at once. Exactly 10 grms. is weighed out into a 100 cc. centrifuge tube. The flour is stirred with

Diagram V.
Results by several methods of glutelin estimation



This method was adapted to give a quantitative estimate of the glutelin present in barley. Magnesium sulphate solution was used as the precipitant instead of ammonium sulphate.

Some of the results by both these methods are summarized above (Diagram V).

These results show that there is a fairly good agreement between the estimation by difference and the direct estimation.

Further study of the methods will probably lead to an accurate method for the direct estimation of barley glutelin.

III.—DETAILS OF THE METHOD USED FOR THE QUANTITATIVE ESTIMATION OF BARLEY PROTEINS.

About 50 grms. of barley is carefully

70 cc. of potassium sulphate (p_H of solution 5.6) corked and shaken in a mechanical shaker for 15 minutes. The pairs of tubes are then balanced by the addition of water and centrifuged at 2,500 revs. per min. for 5 minutes. The supernatant liquid is filtered through cotton wool into a 500 cc. graduated flask. The residue in the centrifuge tube is again extracted in the same way and the process repeated to give five extractions in all. The resulting extracts are made up to 500 cc., and 100 cc. is taken for the determination of total nitrogen present.

Albumin N.—200 cc. of the salt extract is buffered to p_H 4.6 with 20 cc. of buffer solution (equal volumes of normal solutions of sodium acetate and acetic acid) and heated to 82° C. for 20 minutes in a tube carefully

cleaned by dichromate and sulphuric acid. Under these conditions the albumin coagulates into large particles which do not adhere to the tube. The precipitate is filtered off on a coarse filter paper, and the nitrogen in the precipitate determined by Kjeldahl. (Note that the albumin by this method is

probably too high, for the reason explained above, page 106.

Non-protein Nitrogen.—70 cc. of the salt extract is put into each of two 100 cc. centrifuge tubes and 10 cc. of N/10 sodium hydroxide added to each. Two drops of phenolphthalein are added and N/10 copper sulphate run in from a pipette, with stirring, until the violet colour just changes permanently to green. After standing a few minutes the tubes are balanced and the precipitate centrifuged off. The nitrogen in the precipitate is determined by Kjeldahl and represents "protein" nitrogen. That in solution is determined and represents "non protein" nitrogen. The sum of the two is a check on the accuracy of the estimation of total nitrogen of the salt extract and of the "protein" and "non-protein" nitrogen.

Alcohol-soluble Nitrogen. Hordein Nitrogen.—The salt-extracted barley is mixed with 60 cc. of 70 per cent. (by volume) ethyl alcohol. The tube is closed with a rubber stopper and is screwed tightly in the small brass apparatus shown in the diagram.

The tube is then put in a bath, maintained at 82° C. and is shaken at frequent intervals. At the end of 30 minutes the tube is taken out, allowed to cool a minute, unscrewed, balanced, and centrifuged while hot for one minute at 2,500 revs. per min. The alcohol extract is poured into a 250 cc. graduated flask containing a few drops of strong alkali, which prevents deposition of protein from the cooling solution. Two further extractions are made under the same conditions and the total extract allowed to cool and made up to 250 cc. Total nitrogen is determined in duplicate on 100 cc. lots of the solution.

Glutelin Nitrogen.—This is determined by subtracting the sum of the salt and alcohol-soluble nitrogen from the total nitrogen of the sample.

The successive salt extractions are carried through as quickly as possible after one another and similarly the estimations on the solutions are carried out immediately, to minimise bacterial action and denaturation. After the last salt extraction the barley residue is at once mixed with the first lot of alcohol. It is well to carry through this extraction quickly to reduce the possibility of denaturation. The Kjeldahl determination on the extract should be done soon after

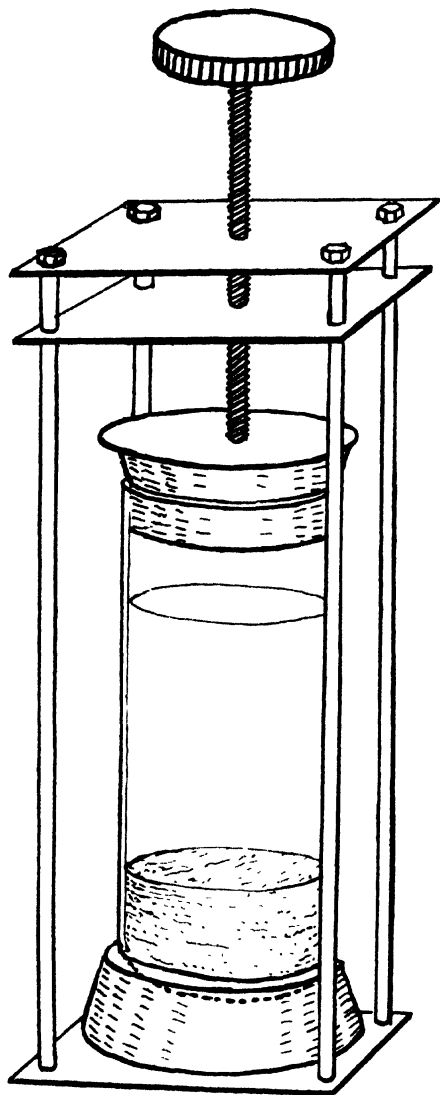


DIAGRAM VI.

APPARATUS FOR ALCOHOLIC EXTRACTION
UNDER PRESSURE.

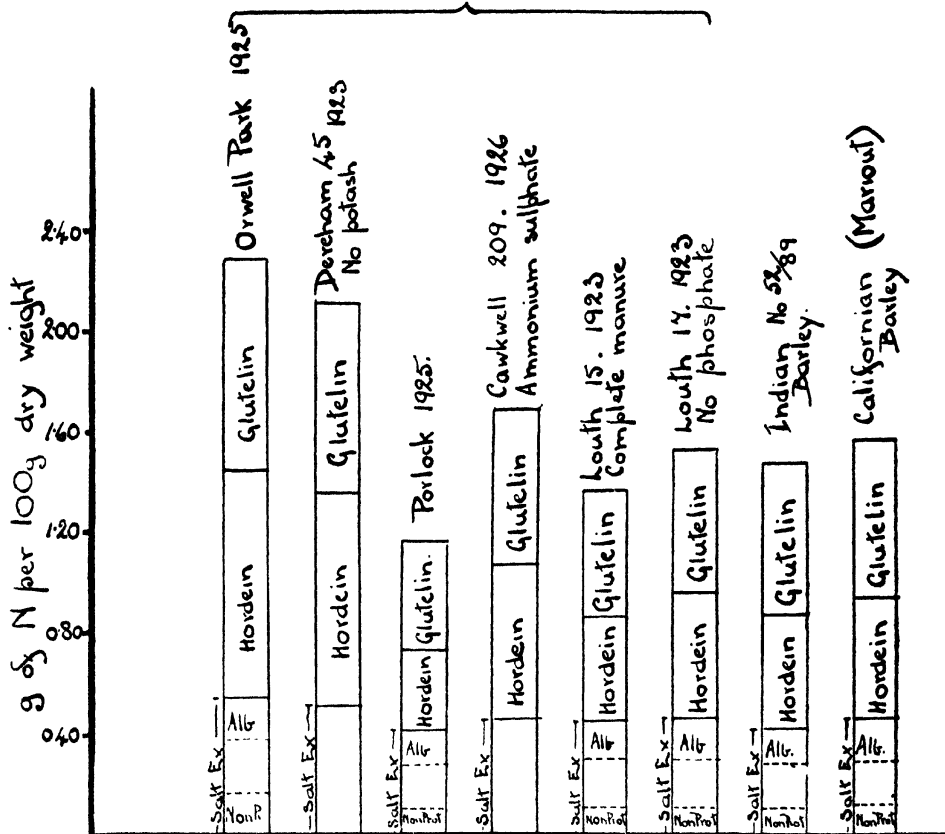
the solution is made up to avoid the possibility of the loss of some nitrogen as ammonia.

The above set of processes is designed to estimate as accurately as possible single proteins or a definite group of proteins and further accuracy has been obtained by standardised procedure.

Among them may be mentioned the Louth barleys which gave better malts than was expected from the appearance of the barley. Porlock barley was the sample with the lowest nitrogen content, and Orwell Park that with the highest during the whole of the experiments.

Diagram VII

Plumage-Archer Barleys.



IV.—RESULTS.

A selection was made of "good" and "bad" barleys from the samples of Plumage-Archer barleys grown under the Institute scheme. Among those chosen were examples which departed from the general trend of nitrogen content with valuation, so that their total nitrogen content was not sufficient to explain the valuation.

The results for a few of the barleys are shown diagrammatically above (Diagram VII.).

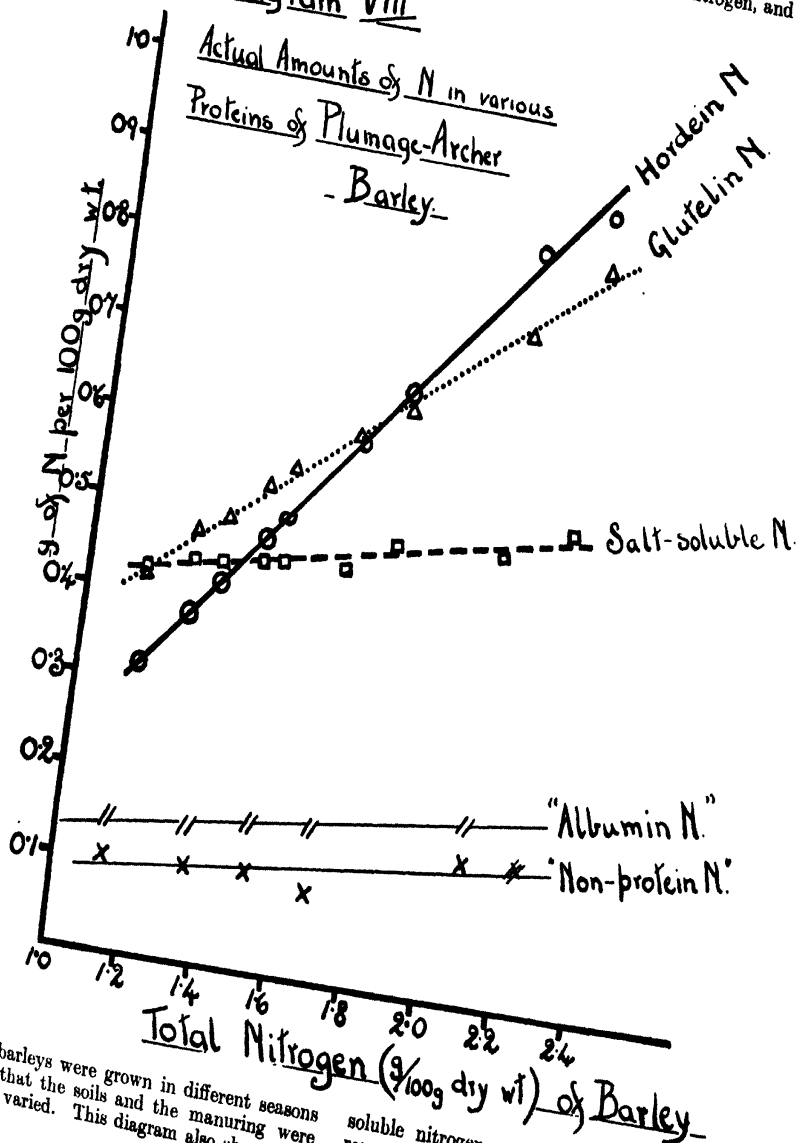
It is clear that no striking irregularities are to be seen in the proportions of different proteins.

When the amounts or percentages (Diagrams VIII. and IX.) of nitrogen in the different protein fractions are plotted against

BISHOP: FIRST REPORT ON BARLEY PROTEINS.

the total nitrogen in the barley an evident regularity runs through the group. It will be noticed from Diagram IX. that

the percentage amount of glutelin remains constant while that of hordein increases with increasing total nitrogen, and the salt

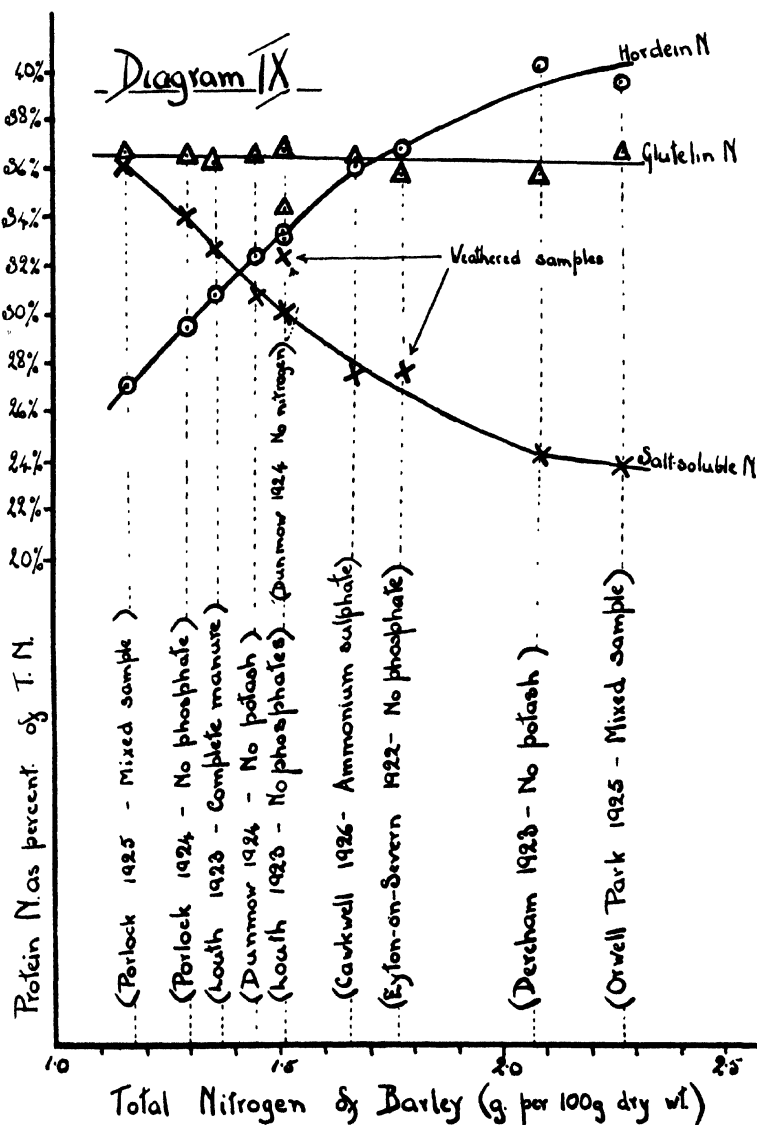
Diagram VIII

the barleys were grown in different seasons and that the soils and the manuring were very varied. This diagram also shows that soluble nitrogen percentage decreases correspondingly. As might be expected, the "albumin" and "non-protein" nitrogen

curves behave similarly to the salt-soluble nitrogen curve. Beaven (25) found that the percentage of alcohol-soluble nitrogen increased in greater proportion than the total nitrogen, which is in agreement with the above conclusion.

and are affected only indirectly by conditions such as soil, climate and manuring.

Section XI. (pp. 118-123) of Mr. Hulton's Report (24) summarises previous work and theories on the relation of the amounts of the various nitrogenous constituents to



For the barleys shown in the curves it follows that the relative proportions of the different nitrogenous substances at maturity depend on the total nitrogen of the grain,

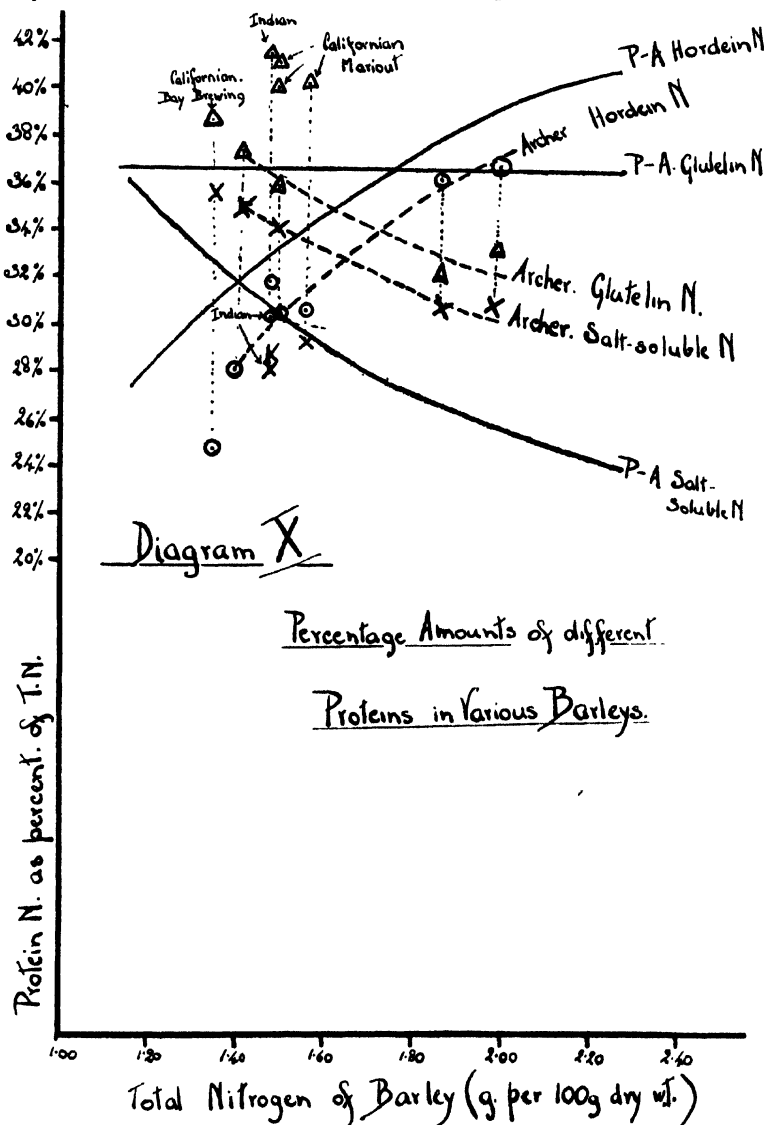
what is referred to as "quality" in barley.

The total nitrogen of the mature barleys used in the above experiments is then a

good measure of the amounts of the separate constituents, and differences in "quality" between these barleys could not be explained as due to differences in amounts of individual proteins apart from the variation in total

pictured as balanced, so that any given amount of total nitrogen would at maturity have settled down to predictable amounts of each constituent.

Plottings of results with other barleys



The smoothed curves for the results of the Plumage-Archer barleys have been given for comparison—"P.-A. salt-soluble," etc.

nitrogen. The total nitrogen content, as is well known, is widely influenced by soil and season. Inside the grain, however, the proportions of constituent proteins may be

together with the Plumage-Archer curves are given in Diagram X.

They indicate that other varieties of barley may have curves similar to those of

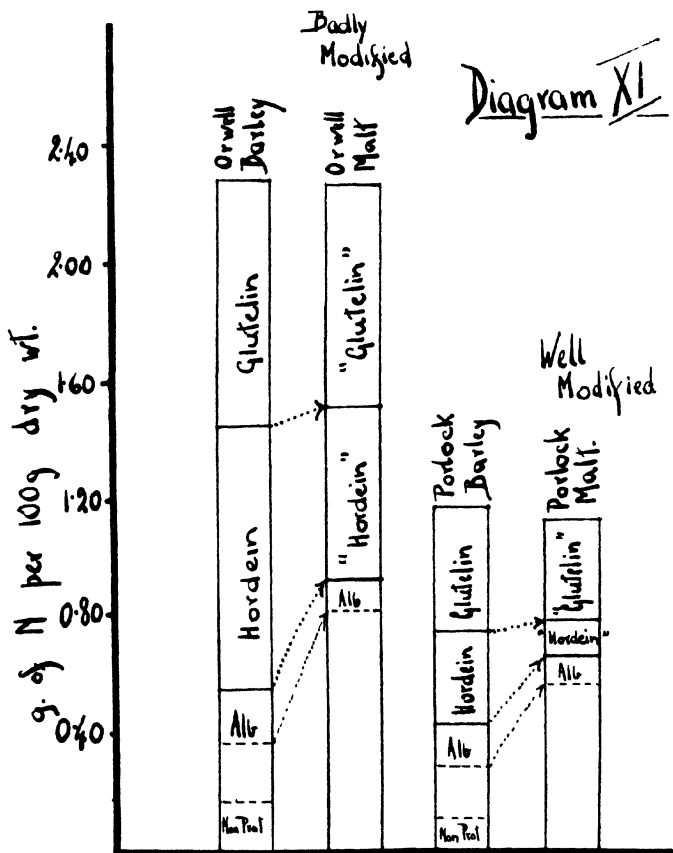
Plumage-Archer. The glutelin percentage of Indian and Californian barleys appears to be higher than that of English barleys, while the percentage of salt and alcohol-soluble fractions is smaller.

Beaven (25) noted that the percentage of alcohol-soluble nitrogen is generally lower with six-rowed varieties.

Various possibilities are suggested by these results. (1) If wheats show a similar behaviour it might be possible to cross

Barleys which have a high glutelin content would then have less protein already salt and water-soluble, and less hordein to break down into such compounds. So that barley varieties with a high glutelin content may be of value in brewing in being equivalent to nitrogen diluents. This deduction is at present very problematical.

My work does not appear to support the suggestion that wide variations in the alcohol-soluble protein may account for



varieties possessing other desirable characters with varieties having a high glutelin percentage, since this protein is chiefly responsible for the baking quality of bread.

(2) Some preliminary experiments indicate that hordein is the chief protein attacked during malting. (See Diagram XI).

This agrees with a comparison of Osborne's (2) and (26) estimates of the proteins in barley and malt, and also with the work of Kraft (27).

differences in "quality" between barleys of the same variety. A great many other factors enter into the determination of "quality." In particular the proteins are broken down by enzymes, and different enzymes (peptase, tryptase, etc.) break them down to different stages—proteoses or peptones, or right down to amino-acids. So that the amount and nature of the proteolytic enzymes will have a large share in determining the nature of the resulting nitrogen

compounds in the wort and beer. Hence the amounts of the different proteolytic enzymes and the acidity conditions under which they act will be important factors in "quality" from the nitrogen standpoint.

COMPARISON WITH RESULTS OF OTHER WORKERS.

In Diagram XII. the results for hordein (hot alcohol extraction after salt extraction) are compared with the results of other workers who extracted directly with alcohol, either in the cold, H. L. Hind (28), Beaven (25), or when warm, Murphy (29), or by boiling under a reflux condenser (unpublished data by courtesy of H. L. Hind). In addition to the hordein, alcohol dissolves other nitrogen compounds. So that boiling alcohol gives a higher result than the hordein estimation; but the small solubility of hordein results in it being incompletely dissolved by cold alcohol, so that the total amount of nitrogen dissolved by this is less than the amount of hordein nitrogen alone.

From a short account (30) of work by Prior on Austrian barleys, it is probable he adopted methods similar to those above. As indicated on the diagram, his estimates of the alcohol-soluble protein cover a wide range.

Recent work in Japan on the amounts of proteins in three varieties of barley has been mentioned in an abstract (31), which is not full enough for an opinion to be formed of the value or bearing of the work.

SUMMARY AND GENERAL CONCLUSIONS.

The main object of the present work was the estimation of the various proteins in barley. A study was made of the conditions which were necessary for doing this. As a result, a method was developed and standardised. The albumin, globulin and breakdown products of protein are first extracted from a sample of barley by salt solution. In this fraction, "albumin nitrogen" and "non-protein nitrogen" are estimated. After the salt extraction hordein is extracted by hot alcohol. The nitrogen in this extract probably represents approximately pure hordein. The remaining nitrogen, after the salt and alcohol extractions, probably represents pure glutelin. Estimations of the amounts of glutelin by two direct methods show tolerable agreement with the estimation by difference

Direct determination of the alcohol-soluble nitrogen in barley without the previous, treatment with salt solution does not satisfactorily estimate the amount of hordein.

Results are given of estimations by the above method of selected samples of Plumage-Archer barley grown under the Institute's scheme in different years, on different soils, and with different manurings.

In these samples, the total nitrogen varied from 1.2 per cent. to 2.3 per cent.

(a) The percentages of glutelin remained constant at 36 per cent. of the total nitrogen, whatever this amount.

(b) The percentage of hordein increased as the total nitrogen increased, rising from 26 per cent. of the total nitrogen when 1.2 per cent. of nitrogen was present to 40 per cent. of the total nitrogen when 2.3 per cent. of nitrogen was present.

(c) The percentage as salt-soluble nitrogen fell from 36 per cent. to 24 per cent. as the total nitrogen increased from 1.2 per cent. to 2.3 per cent.

The analytical figures for mature samples fell on smooth curves between these points, whatever the history of the barley, indicating that for these samples external conditions, while altering the total amount of nitrogen in the grain, appeared to have no influence on the proportions of the proteins in the mature barley. There appears to be a balance between the various proteins which adjusts itself according to the total amount of nitrogen present. For these samples, therefore, total nitrogen is a good measure of the amounts of individual proteins, and, further, the varying "quality" of the mature samples of comparable barleys having equal nitrogen content, is not due to variations in the amounts of individual proteins, such as hordein. The amounts of the various proteolytic enzymes may, however, play an important part in determining "quality."

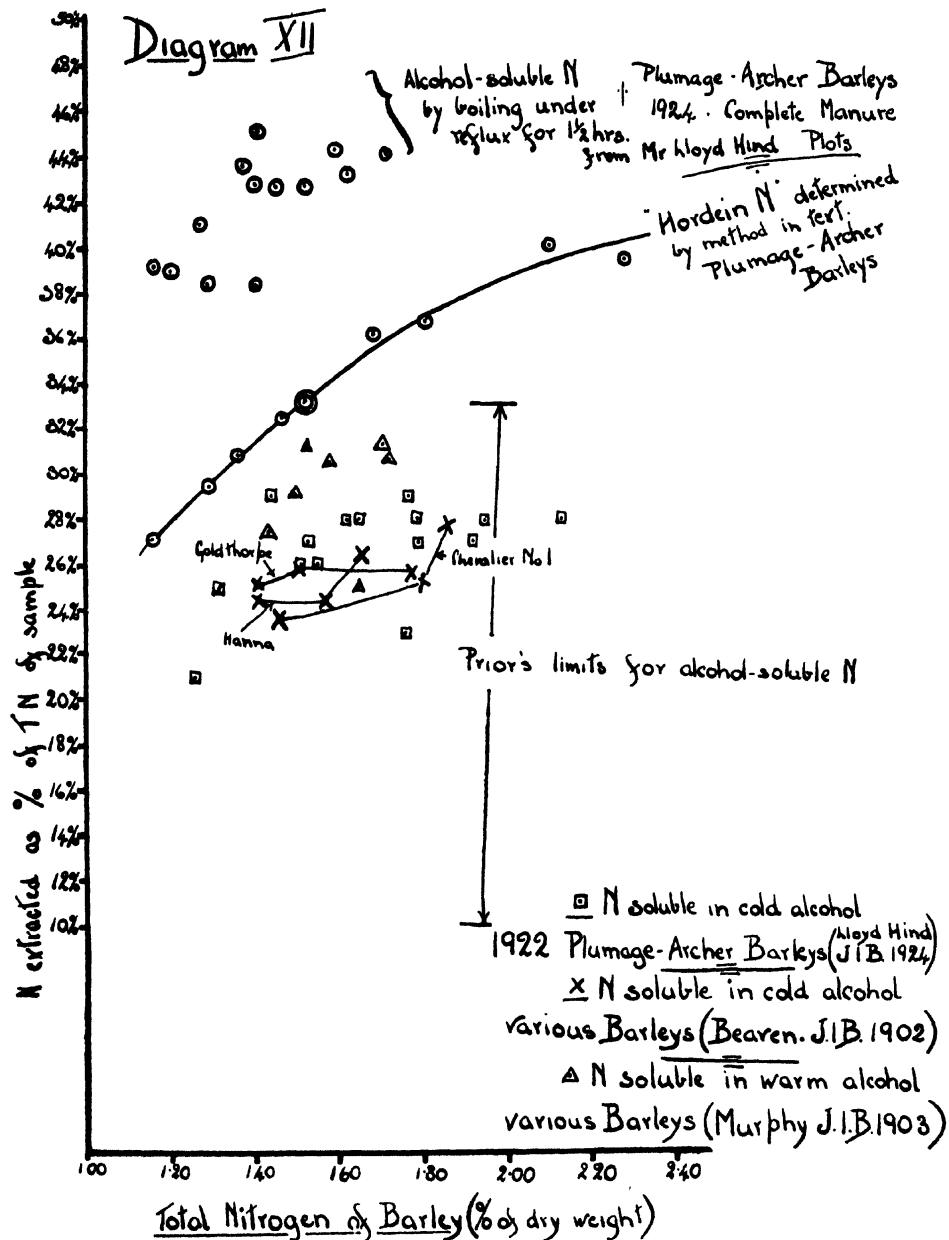
Other barleys, not from the Institute's set, gave curves of apparently similar type, but somewhat different numerical values.

Some preliminary experiments on malt indicate that hordein is the chief protein which is attacked during malting, breaking down to give salt-soluble compounds. The amount of albumin also appears to fall slightly. A possible bearing of this is that barleys having more glutelin, *i.e.*, the protein which appears *not* to give rise to soluble

nitrogen, may be of value as nitrogen diluents.

The existing methods of isolating and

Hordein, having an exceptionally high proline content, cannot be analysed satisfactorily by the present Van Slyke process;



studying the various nitrogen compounds from barley have been investigated, but they have not proved altogether satisfactory.

it is hoped to improve the methods for isolating the albumin and globulin.

I wish to acknowledge valuable advice

from Dr. A. C. Chibnall and from Mr. H. J. Page, B.Sc., during the course of the work, and from Sir John Russell, D.Sc., and Mr. H. L. Hind, B.Sc., F.I.C., in the preparation of this paper.

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THE INSTITUTE OF BREWING RESEARCH SCHEME.

SECOND REPORT ON BARLEY PROTEINS.

COMPOSITION AND QUANTITATIVE ESTIMATION OF THE BARLEY PROTEINS.—II.

By L. R. BISHOP.

THE work on the quantitative estimation of the proteins of the barley grain which was described in the First Report ⁽¹⁾ has been continued with the aim of checking and extending the methods described, in order that they could be applied to a study of the changes occurring during malting. The fractionation in more detail of the various substances extracted by salt solution was of particular interest since the protein breakdown products (very approximately equivalent to the "permanently soluble nitrogen") must necessarily be studied in following the changes during malting. In such a study it was also necessary to know if the methods can be successfully applied to malt as well as to barley. This would not be possible if the proteins of malt and barley were different.

Relation of the proteins of Barley to those of Malt.

Osborne and Campbell ⁽²⁾ in 1896 concluded, from the elementary composition of their preparations, that the proteins of malt were different from those of barley. They concluded that the hordein of barley gave rise in malt to a slightly different alcohol-soluble protein, which they named "bynin." Similarly they considered that the globulin of barley, which Osborne called edestin, was changed to "byn-estestin" in malt.

Luers ⁽³⁾ was unable to find significant differences between his Van Slyke analyses of hordein and "bynin" separated respectively from barley and from malt. The danger of contamination of the alcohol-soluble protein by salt-soluble nitrogenous compounds and carbohydrates is greater in malt than in barley and neither Osborne and Campbell nor Luers employed previous salt extraction to avoid this difficulty. Such contamination probably accounts for the 1 per cent. more carbon, and 1 per cent. less nitrogen in "bynin" (compared with

hordein) on which Osborne and Campbell based the distinction.

Kraft ⁽⁴⁾ found the specific rotation and solubilities in alcohol, water and alkali of hordein and of "bynin" did not differ significantly. The same could be said of his determinations of the amount of glutamic acid in each.

Hence there is no doubt that hordein and "bynin" are very similar. It is still possible that hordein partly degraded by enzyme action during malting may still be alcohol-soluble and so would be extracted mixed with unaltered hordein and the mixture would constitute "bynin." The evidence is, however, against this. I found the ammonia percentage of the hot 70 per cent. alcohol extract of malt (previously repeatedly extracted by salt solution) to be almost the same as that for the hordein of barley.

TABLE 1.

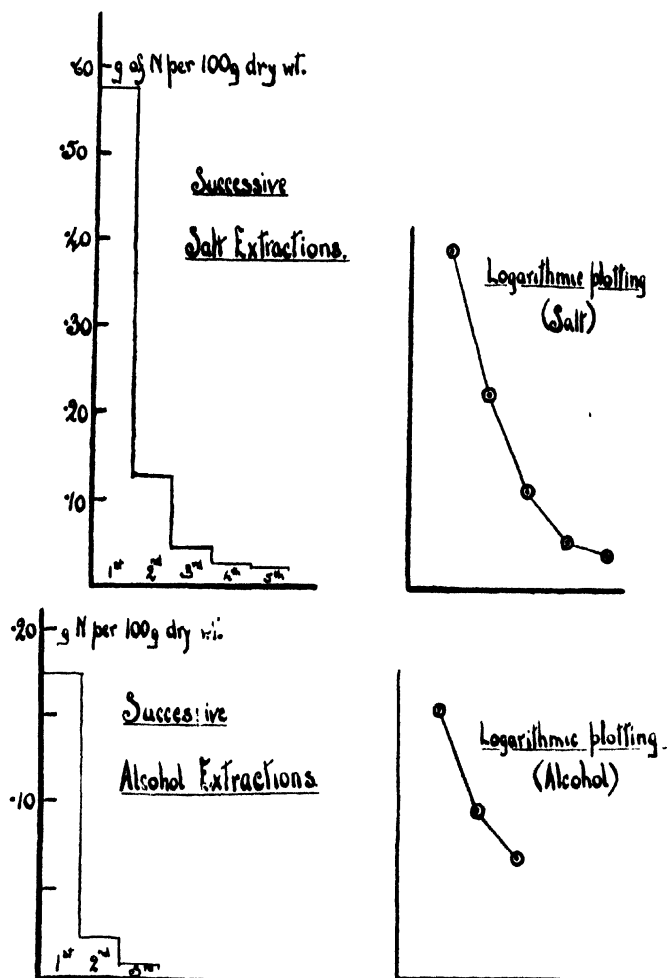
	Ammonia per cent. of alcoholic extract	Values for pure protein.	
Barley	23.3	Hordein	23.3 Osborne
	23.2		23.00 Luers ⁽³⁾
Malt	23.1	"Bynin"	23.38 Hoffman and Gortner
			23.55 Luers ⁽³⁾

Hence it is proposed to discard the name "bynin" and to consider that both hordein and globulin persist throughout malting. Under these circumstances similar methods to those found satisfactory for barley should be applicable to the separation and estimation of the individual proteins of germinating barley or of malt.

Conditions for the Extraction of the Proteins from Malt.

In order to decide whether any modifica-

DIAGRAM 1.
MALT FROM CHISELBOROUGH, 1926.



tions in the extraction methods described for barley in the First Report ⁽¹⁾ were necessary for malt, separate determinations were made of the nitrogen extracted by the successive extraction of two different malts, first by 5 per cent. potassium sulphate solution and then by 70 per cent. alcohol. The quantities and conditions used were the same as those used in the barley extraction. These analyses indicated that the number of extractions used for barley was suitable also for malt. The results for one of the malts are given in Diagram 1, in which the vertical heights of the blocks represent the

amounts of nitrogen dissolved in successive extractions. The logarithmic plotting departs from a straight line owing to proteolytic action and to slow outward diffusion of the proteins. The completeness of extraction was seen to be satisfactory, and it was assumed that the methods would apply equally well to samples from intermediate stages of malting.

If albumin or globulin are coagulated on the kiln the coagulated protein, being insoluble, would appear as glutelin in the estimations. The studies recorded in the Third Report indicate that no serious error

TABLE 2.

	Ammonia per cent. of fraction.		Amide nitrogen of purified protein.
	Barley	Malt	
Albumin	9.84, 8.64	—	9.40 per cent. (Luers and Landauer) 9.29 per cent. (Bishop)
Globulin	8.93	10.5	9.02 per cent. (Bishop)
Hordein	23.3, 23.2	23.1	23.3 per cent. (Osborne); 23.00 per cent. 23.3 (bynin) (Luers); 23.38 per cent. (Hoffman and Gortner)
Glutelin (Difference)	12.3	11.7	11.38 per cent. (Larmour) (⁵) 12.3 per cent. (Bishop)

arises in this way, and, taking this into consideration, the methods developed for barley would appear to be applicable to a study of malting.

Estimations of the amino-nitrogen showed that the slight degradation of proteins which takes place during the salt extractions occurs chiefly in the solid particles not in the solution. This is checked immediately the residue is mixed with the alcohol (under $2\frac{1}{2}$ hours from the commencement of extraction) and the salt solution is fractionated as soon as possible. It is considered that under these conditions proteolytic activity is not a source of serious error, even in the green malts where proteolytic activity is relatively high.

Ammonia percentage of the proteins of Barley and Malt.

This useful index (equivalent to the amide nitrogen of the Van Slyke analysis) was used in the First Report to show the purity of the alcohol extract. Its use has now been extended to the other fractions, and the table above (Table 2) gives evidence for the assumption that the total nitrogen determined in each of the fractions comes almost entirely from that protein which it is supposed to represent.

Fineness of Grinding.

Early studies showed the importance of this factor in the analysis of barley. In the earlier work the grinding was made as even as possible by the use of an adjustable large cone coffee mill. This was not altogether satisfactory, especially with barleys having a tough structure. Since then a mechanical mill (the "Wiley" mill) has been tested. This mill grinds, without heating the material,

by the cutting action of knives. The material passes through a sieve out of the grinding region as soon as it has reached the necessary degree of fineness.

The following table illustrates the very large effect on the apparent salt-soluble nitrogen (and in consequence on the other fractions) of varying degrees of fineness of grinding. It also shows that even half millimetre fineness is not as good as the "coffee mill" grinding, which reduces most of the material to a finer state of division, but leaves some large particles. In consequence, in all the later work the material has been ground first as fine as possible in the "coffee" mill and then reground in the Wiley mill using the $\frac{1}{2}$ mm. sieve to ensure evenness.

It will be seen that the hordein nitrogen is affected least and consequently is more reliable. Barley 166c was of fairly low

TABLE 3.—Effect of Grinding on the Analyses.

Barley.	Method of Grinding.	Salt-sol.	Hordein.	Glutelin.
166c	1 mm. Wiley	25.6	29.1	45.2
(Archer	$\frac{1}{2}$ mm. Wiley	31.2	28.7	40.0
N.I.A.B.	"Coffee Mill"	34.9	27.7	37.3
1924).	"Coffee Mill" and			
	$\frac{1}{2}$ mm. Wiley	36.2	27.9	35.8
	Total nitrogen on dry			
	barley 1.42%			
140	1 mm. Wiley	23.6	34.2	42.3
(Archer	$\frac{1}{2}$ mm. Wiley	27.5	34.8	37.6
N.I.A.B.	"Coffee Mill"	30.8	36.3	32.8
1923).	"Coffee Mill" and			
	$\frac{1}{2}$ mm Wiley	30.1	35.2	34.7
	Total nitrogen on			
	dry barley 1.98%			

Note.—Sample numbers here and elsewhere in these Reports refer to barleys described in Sir John Russell's Reports on the Barley Research.

nitrogen content, and the slight increase of apparent hordein with coarse grinding may be explained as due to extraction of previously unextracted salt-soluble nitrogen. In barley 140 the nitrogen content was high, and apparently the larger amount of hordein was not efficiently extracted from the coarse particles, since slightly larger amounts are obtained from the finely ground samples.

Fractionation of the Salt-Soluble Compounds.

The salt extraction, it will be recalled, dissolves out from the barley the fully built up proteins, albumin and globulin,

the methods of fractionation then adopted.

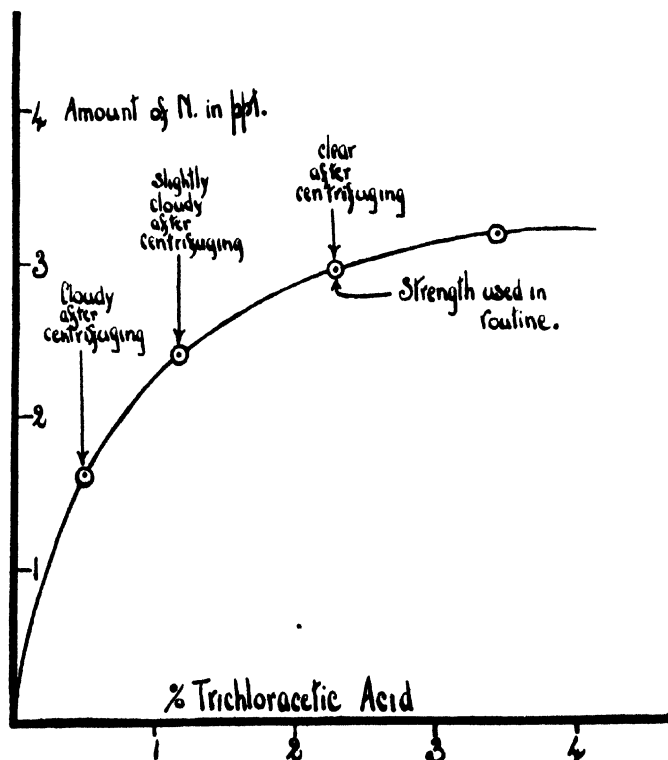
Albumin.

The difficulty encountered in the estimation of albumin referred to in the First Report ⁽¹⁾ has been overcome by allowing the extract to stand with the acid buffer solution to remove that part of the globulin which is precipitated as the acid compound. The extract is then filtered, and used for the albumin estimation.

Total Proteins.

Brief reference was made in the First Report ⁽¹⁾ to the use of trichloroacetic acid

DIAGRAM II.
NITROGEN PRECIPITATED FROM SALT EXTRACT BY VARIOUS CONCENTRATIONS OF TRICHLOROACETIC ACID.



and also protein breakdown products, such as proteoses, peptones, amino-acids and other simple nitrogen compounds. In the work described in the First Report ⁽¹⁾, only the albumin and non-protein nitrogen were estimated. Further work has now been carried out with the object of extending

for the estimation of total proteins (i.e., albumin+globulin). Further investigation of the method has shown it to be satisfactory as applied to barley and malt.

Luck ⁽²⁾ gives a list of papers which show that trichloroacetic acid (at 2.4 per cent. concentration) is a specific precipitant for

fully built-up proteins, and is quantitative for albumins and globulins. My experiments showed that the amount of nitrogen precipitated from barley extracts is affected by the concentration of the precipitant. See Diagram II. (p. 319). The strength chosen (2.27 per cent.) is probably about the best, since the slow increase with higher concentrations is attributed to precipitation of the higher proteoses.

The free amino nitrogen of this precipitate is considered to be a measure of the amount of fully built up protein present. In several proteins Wilson (?) found this to range from 2.5 per cent. of the total nitrogen. Van Slyke demonstrated that it corresponds to the amount of the nitrogen in the form of the ϵ group of lysine. Calculating from my Van Slyke analyses of albumin and globulin (which are preliminary), and assuming equal amounts of each, the value on these assumptions should be 4.52 per cent. Wilson (?) showed that hydrolysis occurred in the determination of the free amino-nitrogen by means of the Van Slyke method, so that it is not entirely satisfactory. The result of my determinations of the free amino nitrogen of about 5 per cent. (duplicates 5.01 per cent. and 4.85 per cent. with 15 minutes' shaking at 17° C.) indicates that the major part of the trichloroacetic precipitate consists of fully built-up protein. It is interesting to note that the use of the ratio of free amino to total nitrogen as a measure of the complexity of protein degradation products was introduced by Horace Brown (8) and that the Van Slyke method is a modification of his method.

Proteoses, etc.

No method for the estimation of proteoses and other intermediate protein breakdown products was described in the First Report (1).

In the experiments carried out this year an estimation of the amount of nitrogen in this form has been obtained by a difference method. It represents the difference between the amount of nitrogen left in solution by trichloroacetic acid, and that left in solution by the copper hydroxide precipitation. Such a difference method is unsatisfactory, and in one barley a small negative result was obtained. The figures obtained however, probably have a relative value. The method used by Luck (9) appears to be preferable. He adds kaolin to the solution after

trichloroacetic acid precipitation (of liver and muscle extracts), and states, with references and experiments to support it, that kaolin adsorbs proteoses and peptones, but does not adsorb amino-acids. It is difficult to test critically this specificity with barley extracts, but a determination by the Van Slyke method of the free amino-nitrogen of the compounds adsorbed under these conditions indicates that the claim is substantially correct. The amino nitrogen was 10.7 per cent. of the total nitrogen (after 15 minutes' shaking at 17° C.). Wilson (?) found 8 per cent. of the nitrogen of proteoses as free amino nitrogen and 27 per cent. with peptones. It is proposed to use the kaolin adsorption method in future, and discard the copper precipitation. Comparative estimations of the proteoses by the difference method and by kaolin adsorption showed that the latter gave higher results with a corresponding reduction of the "non-protein" or amino-acid nitrogen.

The following section gives details of the procedure which has been followed in all the analyses discussed in the Third Report, together with a modification to be used in the future. They include the methods adopted in the First Report (1) with additions and slight modifications in procedure. It is considered that the fractionations adopted are sufficient to give sound estimates of the amounts of nitrogen in different states of complexity.

Details of the Methods used for the Quantitative Estimations of the Proteins of Barley and Malt.

Thousand corn weight is determined in triplicate on 20 gm. samples.

The dry grain (10 per cent. moisture or less) is finely ground in a "coffee" mill, and re-ground in a "Wiley" mill, using the $\frac{1}{2}$ mm. sieve.

Moisture and total nitrogen determinations are made as described in the First Report (p. 109).

Salt Extraction.

Exactly 10 grms. of material is stirred with 70 ccs. of 5 per cent. potassium sulphate solution (p_H 5.6) in a 100 cc. centrifuge tube. This is shaken for 15 minutes, and then centrifuged for 5 minutes at 2,500 revs. per min. The supernatant liquid is filtered through cotton wool into a 500 cc. flask containing a little toluene. The extraction of the residue is repeated in the same way to give five extractions in all. The resulting

extract is made up to 500 cc. and 100 cc. taken for determination of total nitrogen.

Albumin Nitrogen.—140 cc. of the extract is buffered to p_H 4.6 by adding 10 cc. of acetate-acetic buffer (equal volumes of normal solutions of acetic acid and of sodium acetate). The solution is allowed to stand for 1 hour, and is then filtered through a No. 41 Whatman filter paper into a 200 cc. boiling tube. This tube has previously been carefully cleaned with chromic acid. The tube is placed for 20 mins. in a sloping position half immersed in a bath maintained at 82° C. Under these conditions, a steady circulation is maintained, and large even coagula are formed which do not adhere to the tube. The precipitate is filtered off through a No. 41 Whatman filter paper, and washed with hot water. The nitrogen content of the precipitate is then determined, and the necessary blank for the filter paper, etc., deducted.

Total Protein.—10 cc. of 25 per cent. trichloroacetic acid solution are added to 100 ccs. of extract in a 150 cc. centrifuge flask. This is allowed to stand 1 hour, and is then centrifuged. The nitrogen is determined in the precipitate (total protein) and in the solution. The sum of these amounts should be equal to the total salt-soluble nitrogen.

Globulin Nitrogen.—An estimate can be obtained of the globulin nitrogen by subtracting the albumin nitrogen from the total protein nitrogen.

"Non-protein" Nitrogen.—This was determined as described in the First Report (p. 110).

Proteose and Peptone Nitrogen.—An estimate of the nitrogen in this form has previ-

ously been obtained by subtracting the "non-protein" nitrogen from that left in solution by trichloroacetic acid.

DIAGRAM III.

In future it is proposed to dispense with the copper precipitation previously employed for determining the non-protein nitrogen, and proceed as follows:

The trichloroacetic acid precipitation is carried out in duplicate, the nitrogen in the precipitate giving, of course, total protein. The clear solution, after centrifuging, is poured into another 150 cc. centrifuge flask, and 2 grms. of acid-washed kaolin added, well shaken and centrifuged off. The duplicate fractions are combined for the nitrogen determinations. The nitrogen adsorbed on the kaolin represents proteose and peptone nitrogen (a blank determination of the nitrogen in the kaolin must be made). The nitrogen in solution represents the nitrogen in the form of simple compounds, such as amino-acids (grouped under the term "non-protein" nitrogen).

In the shortened form of the estimation the total nitrogen of the salt extract is determined in duplicate on 200 ccs. samples and fractionations are not made.

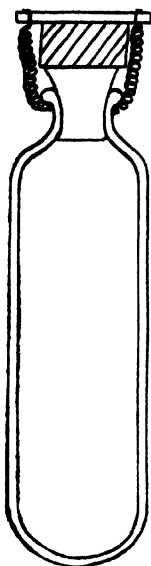


TABLE 4.
ACCURACY OF KJELDAHL ESTIMATIONS OF FRACTIONS.

Sample No.	cc. of standard acid (approx. N/10) required in the estimation of								
	Total Nitrogen.	Salt Extract. Total nitrogen per 100 cc.				Copper soln. (ex 140 cc.)	Trichloroacetic acid ppt. (ex 100 cc.)	Trichloroacetic acid soln. (ex. 100 cc.)	Alcohol Extract (100 cc.)
		Direct	From Copper pptn.	From trichloroacetic acid pptn.	Copper ppt. (ex 140 cc.)				
1	19.44 19.39	5.63	5.66	5.75	5.25	2.68	2.77	2.98	12.55 12.56
2	19.78 19.69	6.92	6.92	6.88	5.95	3.73	3.20	3.68	11.93 11.81
3	18.85 18.89	8.55	8.67	8.68	6.91	5.23	3.47	5.21	9.58 —

The sample numbers refer to the first three samples in malting expt. II.

Hordein Nitrogen.

The alcoholic extraction is carried out as described in the First Report (1), but a more convenient type of centrifuge tube and fittings is used. The arrangements can be seen in Diagram III. (p. 321) The modified form of tube is stronger than that previously described, and springs are used to hold the rubber stopper in position instead of the screw in the older form.

ACCURACY OF THE METHODS.

The individual values obtained in each

analysis are all checked (except the albumin value) either directly by duplicates or indirectly. Examples showing the order of agreement found are given in Table 4 (p. 321.)

The accuracy which is attained in any single set of estimations has been checked by repeating the extractions from the beginning on fresh samples. Table 5 gives some of these duplicate results from which an idea of the probable error of any determination can be gained.

TABLE 5
ACCURACY FROM REPLICATES OF EXTRACTIONS.

Nitrogen per 1,000 corns in the form of									
Malting Expt. III.	Total Nitrogen.	Salt soluble.	Hordein	Glutelin	Albumin	Non-protein	Total protein	Globulin	Protease
Sample 1.									
a	-	270	258	270	101	132	170	070	—023
b	807	272	264	264	097	131	178	081	—026
Average	—	270	261	267	099	132	174	076	—025
Sample 2.									
a	-	275	259	261	085	093	173	088	012
b	795	268	265	263	094	089	154	060	021
Average	—	272	262	262	089	091	164	074	017
Sample 3.									
a	-	294	247	242	-	107	172	073*	012
b	783	286	251	237	099	121	170	071	004
Average	—	290	249	240	—	114	171	072	008

* Using albumin value from (b).

SUMMARY.

The conditions and accuracy of the methods, described in the First Report, for the estimation of the separate proteins of barley, have been checked and slightly modified, and the methods have been amplified with the object of making a study of malting.

It is concluded that Osborne and Campbell's "bynin" in malt can be regarded as almost, if not quite, the same as the hordein of barley, and the distinction has been dropped. It is considered better to drop also the term "byndeustin" and refer to barley globulin throughout.

The quantities and conditions employed for the extraction of the proteins of barley have been found satisfactory also when applied to malt.

The more detailed fractionation of the salt-soluble constituents has been examined experimentally and standardised conditions of procedure are described.

Determinations of the ammonia nitrogen

percentage of the various fractions give evidence of the purity of the protein estimated. Results are given showing that checks and duplicates agree closely.

The great importance of fineness and evenness of grinding has been demonstrated, and the best method found is described.

I am very grateful to Dr. A. C. Chibnall for his supervision during the course of this work.

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Harpenden.

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- ² T. B. Osborne and G. F. Campbell. *J. Amer. Chem. Soc.*, 1896, 18, 542.
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- ⁴ W. Kraft. *Z. ges. Brauw.*, 1910, 33, 193 and 205.
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- ⁶ J. M. Luck. *J. Biol. Chem.*, 1928, 77, 1.
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THE INSTITUTE OF BREWING RESEARCH SCHEME.

THIRD REPORT ON BARLEY PROTEINS.

THE CHANGES UNDERGONE BY THE NITROGENOUS CONSTITUENTS OF BARLEY DURING MALTING.—I.

By L. R. BISHOP.

THIS report presents for the first time a balance sheet of the changes throughout malting of all the main nitrogenous constituents or groups of constituents in the barley grain. The suggestion of the few analyses of malt available [one by Osborne and Campbell (¹) and some by myself (²)] was that it was chiefly hordein which broke down during malting to give salt-soluble products. This study presents a clear picture of what happens, but it is found to be a more complicated process than a simple breakdown of hordein leaving the glutelin unattacked.

To supply the necessary background to this picture it will be of advantage to give a brief summary of some of the relevant facts which have previously been established in the germination of barley and in protein chemistry.

The structure of the barley grain is well-known. During germination the scutellum or inner face of the embryo or germ secretes enzymes (cytase, diastase, proteases, etc.) which attack the materials of the endosperm rendering them soluble so that they are absorbed by the developing embryo. The action of the various enzymes slowly penetrates from the proximal end of the grain near the scutellum to the distal end. The action of the other enzymes probably follows the action of cytase, which renders the cell walls permeable ("modification").

The proteins which are the subject of this study are very complicated bodies built up by linking together of amino-acids. Each protein contains some of nearly every one of the twenty-five or so amino-acids which are known. Each amino-acid is both an acid and a base, and the linking together is effected by the combination of the basic NH_2 (amino) group of one amino-acid with the acidic COOH (carboxyl) group of another amino-acid to give what is known as the

peptide group ($-\text{CO}-\text{NH}-\text{CH}-$). In this way large numbers of molecules of amino-acids are linked together in chains, or more probably complicated structures involving rings, to form the final protein. The completed protein probably has a molecular weight of the order of 20,000 to 60,000.

The two chief proteins of the endosperm are hordein (an alcohol-soluble prolamins) and a glutelin (alkali-soluble). These are attacked during germination first by peptases which commence to reverse the combination process forming bodies (proteoses, peptones, etc.) which are still complicated. These are in turn attacked by tryptases and then ereptases which break them down finally to the constituent amino-acids. Since these compounds are the common basis of all the proteins, the breakdown products at this stage cease to be identifiable as having arisen from one or other of the original proteins of the endosperm. As the breakdown products become less complex they become more soluble and diffusible, and so can be absorbed by the developing embryo and resynthesised to proteins. Brown (³) showed that in this way during malting the nitrogen of the embryo rose from 15 per cent. to 40-50 per cent. of the total nitrogen of the grain.

In this report the word embryo is used to denote the whole of the young growing plant or germ, and so includes both the plumule or acrospire and the rootlets.

The suggestion is made in this report that towards the end of the period on the floor the degradation of proteins in the endosperm and the upgrade processes in the embryo have reached a state of approximate balance. This has been found of great assistance in interpreting the results of germination and the effect of altered conditions during this process on the composition of the malt at the end.

The materials for the investigation were obtained, through the courtesy of Messrs. J. W. Green, Ltd., from malt on the germinating floors and kilns of their maltings at Luton.

METHODS.

At each sampling small samples were taken at various places and at various depths on the malting floor or kiln. This sampling was carried out more carefully in Experiments II and III. The mixed sample was immediately taken to the laboratory and in Experiments II and III samples were taken for the estimation of moisture and 1,000 corn weight. The main bulk of the material was dried in vacuo at 40° C. (104° F.) for one hour. It was then cut up coarsely by the knives in the Wiley mill and dried in vacuo again for several hours. The small leakage of air through a tube fitted with a fine capillary tube was used to sweep out the moisture from the oven. This method was adopted since it was the best practical means which could be found for drying as rapidly and completely as possible without causing enzyme action or modification of the

physical state of the proteins. The dried material was ground first in a "coffee" mill and then in a "Wiley" mill, using a $\frac{1}{2}$ mm. sieve, and analysed as soon as possible.

Since the formation of the breakdown products is of interest here a full analysis of the protein distribution was carried out, using the methods described in the Second Report (*) (pp. 320-22).

RESULTS.

Owing to the long and involved processes it has only been possible so far to carry out studies of the behaviour of the nitrogenous bodies during three complete maltings. These experiments, however, agree in the general idea which they give of the changes occurring during the operation. Experiments I and II were on English two-rowed barley. They agree closely and are discussed together. Experiment III differed in that it was carried out on a Chilean six-rowed barley of higher nitrogen content and that the temperature at the beginning and end of the period on the floor was much higher.

DIAGRAM I.
EXPT. II.

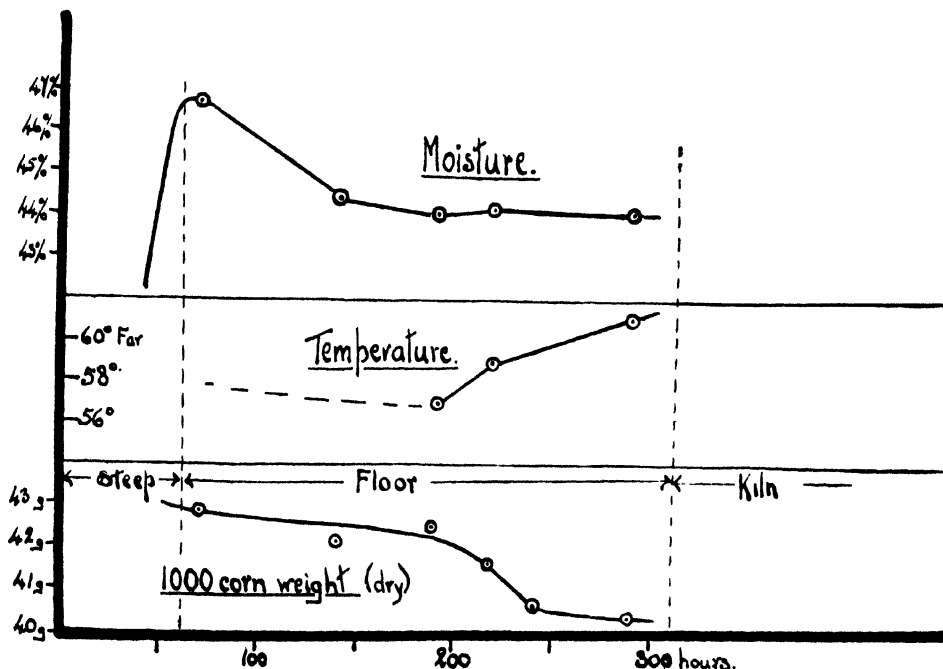
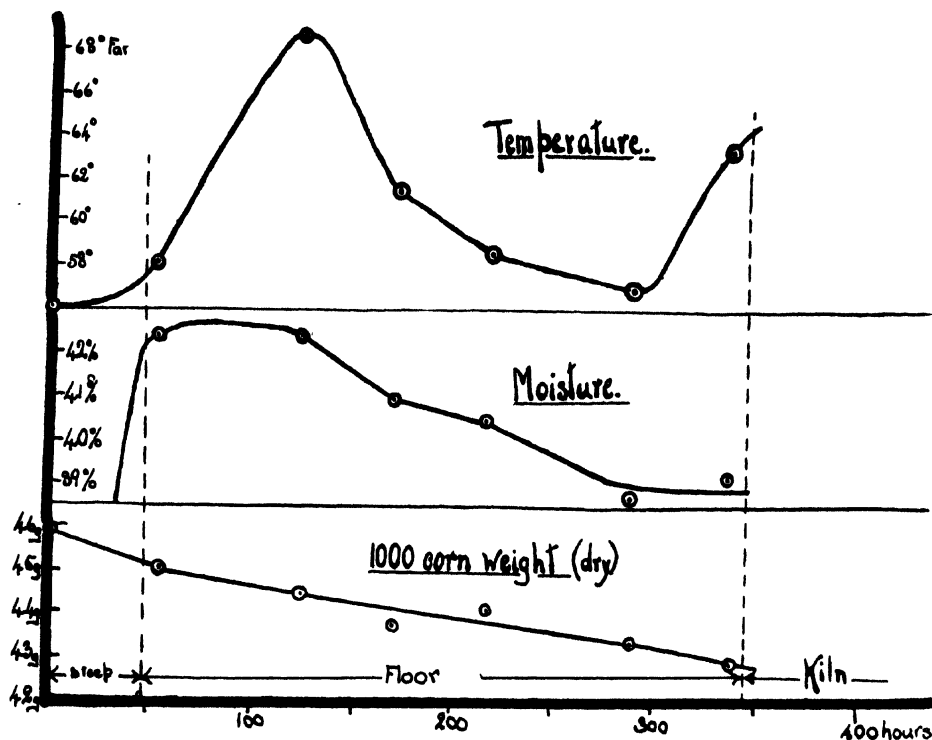


DIAGRAM II.
EXPT. III.

Hence this experiment is discussed separately.

In Experiment I the temperature on the floor remained fairly constant at about 56-60° F. (but notes were not taken). Details of the changes in temperature, moisture and 1,000 corn weight (dry and with rootlets) in Experiments II and III are given in Diagrams I and II. In Experiment II the temperature was fairly constant, while in Experiment III, as noted above, it showed wider fluctuations, and a correspondingly rapid growth of the germ and rootlets took place at the beginning of the flooring period. It is interesting to note that the moisture content while on the floor fluctuates less than might have been expected, especially during the withering stage. The fall in 1,000 corn (with rootlets) weight gives an approximate measure of the amount of respiration and steeping loss.

Tables of the results of the estimations of the amounts of nitrogenous constituents at the various stages are given as an appendix.

Unless stated otherwise, the analyses are of the whole grain together with rootlets, if any. The unit in Experiment I is grms. of nitrogen in the form of the various fractions per 100 grms. of dry barley and rootlets. Since carbohydrate material is lost during malting by respiration a better (*i.e.*, constant) basis for comparison is the amount of nitrogen in 1,000 corns (and rootlets), and this is used in Experiments II and III. However, the percentage of the total weight lost by respiration is not large, so that the diagrams of Experiment I are comparable with those of the other two.

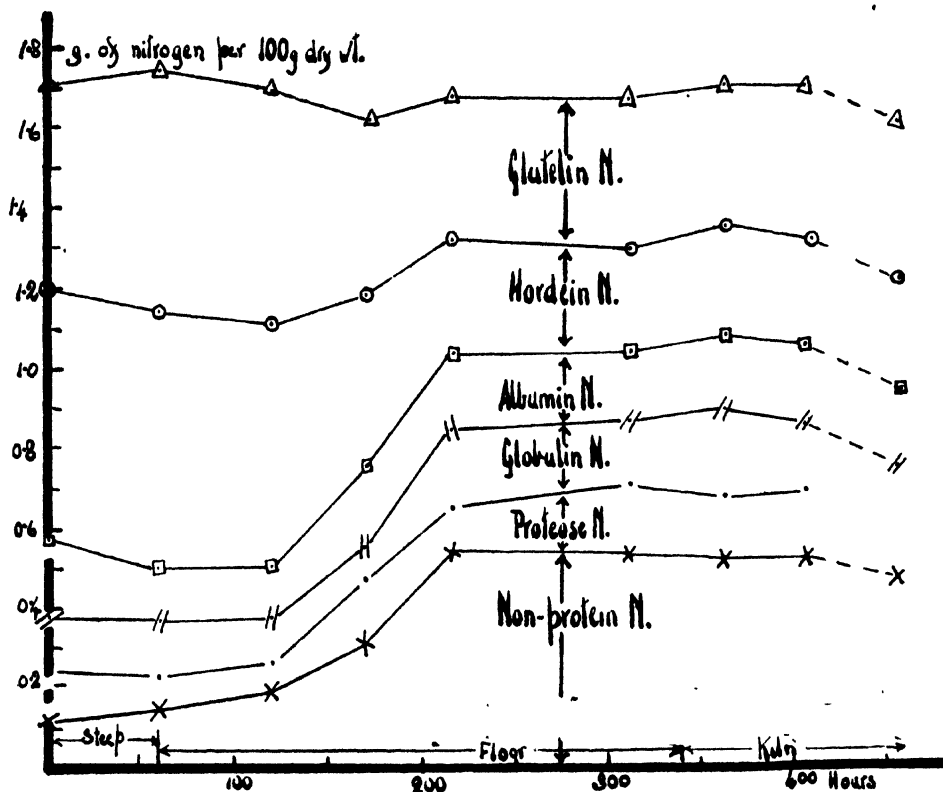
DISCUSSION.

It has been shown in the Second Report (⁴) (p. 316) that it is probably better to regard the proteins of malt and hence those of intermediate stages as identical with those of barley. This assumption is made in the following discussion.

The changes which occurred in all the

DIAGRAM III.

EXPT. I.—Changes in all Constituents during Malting.



nitrogenous constituents (or groups of constituents) in each experiment are given in Diagrams III, IV, and V. (pp. 326, 327 and 328). At any given time the amount of each of the constituents found is given by the vertical distance between the two curves bounding the space in which its name appears. It is not possible without a great deal of confusion to plot in the usual way all the changes studied on one diagram. The height of the top curve from the base represents consequently the total nitrogen, and this method of plotting gives a clear idea of the proportion of the total nitrogen apparently involved in the changes. The successive plottings in these diagrams may be said to represent a series of 'balance sheets' in which is shown the proportion of the total nitrogen which is in each form at successive times.

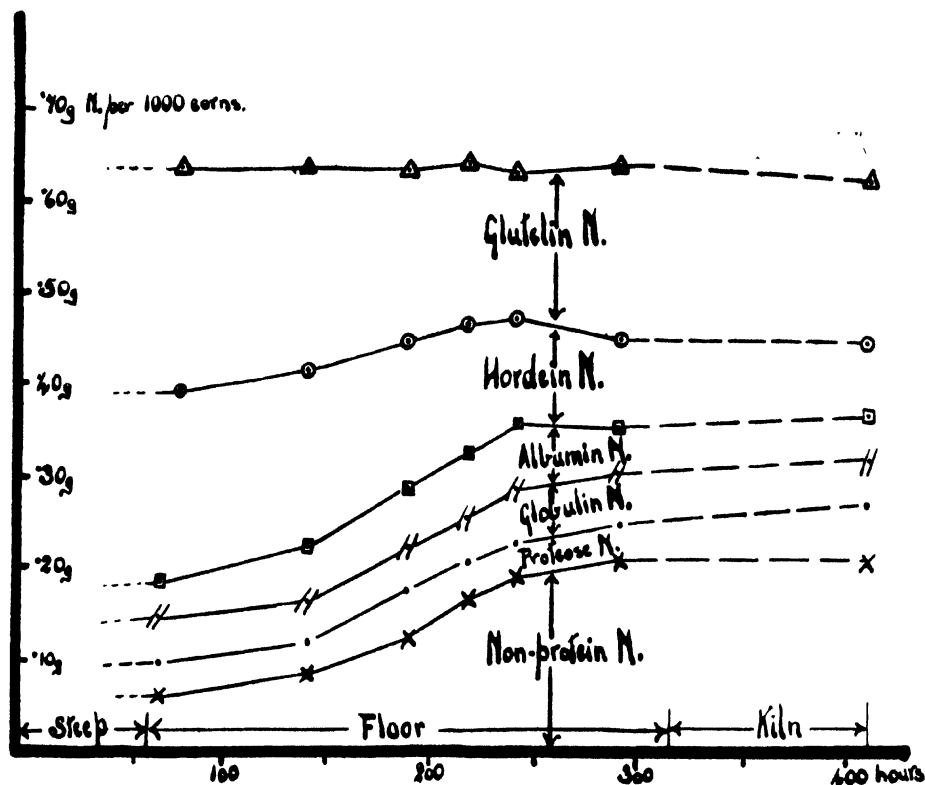
Course of the breakdown of Hordein [and Glutelin.

The graphs of the changes in the amounts of the three main fractions in the first two experiments (Diagrams VI and VII p. 328 and 329) indicate that three fairly well defined stages may be distinguished. During the first 100 hours from the beginning of steeping very little happens. There is of course some loss of nitrogen to the steep water, but it is difficult to trace to which fractions this belongs as at the same time there is a commencement of hydrolysis of hordein and glutelin to give salt-soluble compounds.

During the next 100 hours or so there is a very rapid attack on the hordein and glutelin, indicated by the fall of the corresponding curves and the rise of that representing salt-soluble nitrogen. (Diagrams VI and VII.)

DIAGRAM IV.

EXPT. II.—Changes in all Constituents during Malting.



During the rest of the period on the floor hydrolysis *appears* to cease almost entirely in spite of the fact that the substrates do not appear to be exhausted.

The slow initial attack is easily understood, and is due to the time taken by the water to soak into the grain and to the slow initial liberation of the enzymes.

In the second period the rates of breakdown are high. This is more clearly seen in Diagram VIII and IX (p. 330) where the rates of disappearance are plotted. At first glutelin disappears at about the same rate as hordein. After this the rate of hydrolysis of glutelin appears to fall off while that of hordein remains high. Finally, in the third stage the apparent rate of hordein hydrolysis falls off and the amount of glutelin probably increases slightly.

These phenomena can be explained when it is considered that two separate processes are taking place in the germinating grain: (a) hydrolysis in the endosperm of the insoluble proteins (hordein and glutelin) to form soluble degradation products which are transported to the embryo (b) re-synthesis in the embryo to proteins.

Assuming that glutelin is rebuilt in the embryo, then the amount found in the analysis is the result of the equilibrium between the downgrade process in the endosperm and upgrade process in the embryo. Hashitani⁽⁵⁾ has shown that walt rootlets contain proteins soluble in 10 per cent. sodium chloride solution (these may be assumed to be albumin and globulin) and in 0.25 per cent. sodium hydroxide solution (probably glutelin) as well as amino-acids

DIAGRAM V.
EXPT. III.—Changes in all Constituents during Malting.

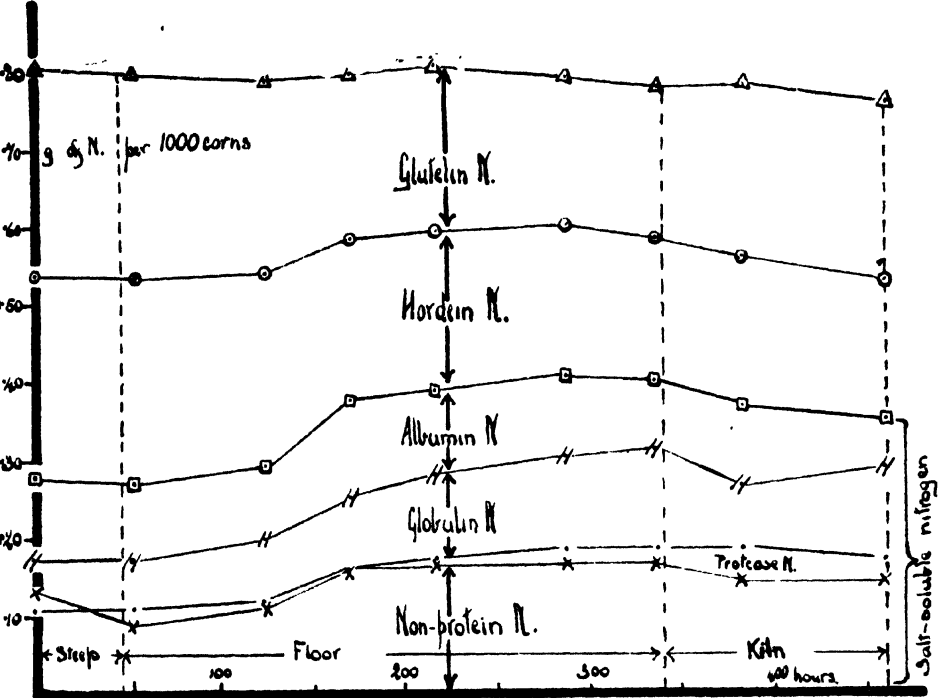


DIAGRAM VI.
EXPT. I.—Changes in Main Fractions during Malting.

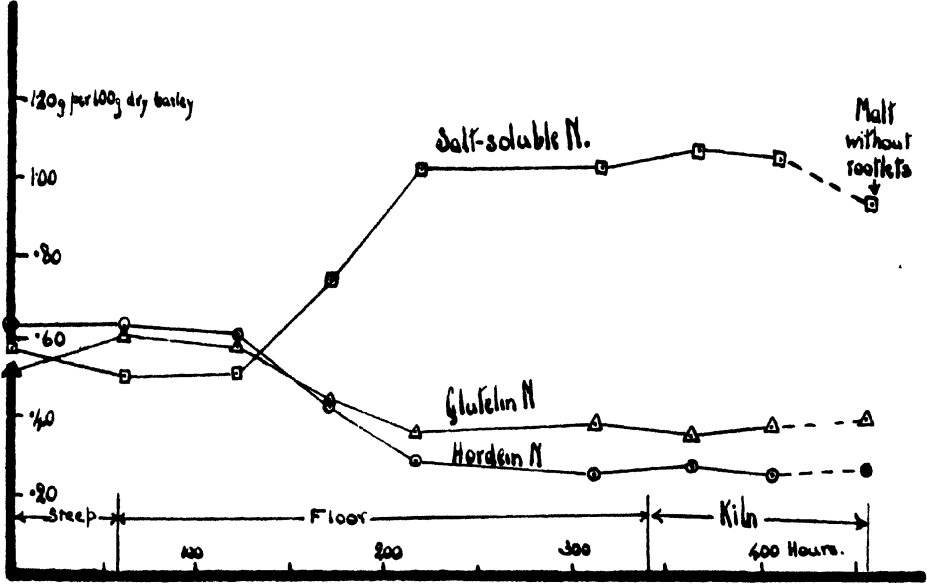
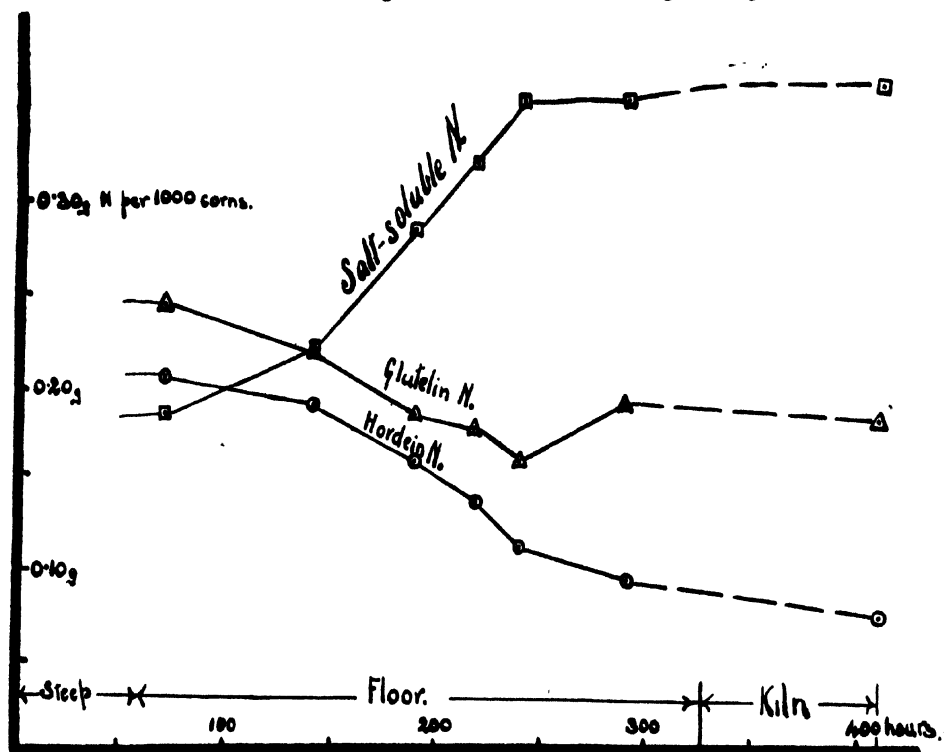


DIAGRAM VII.

EXPT. II.—Changes in Main Fractions during Malting.



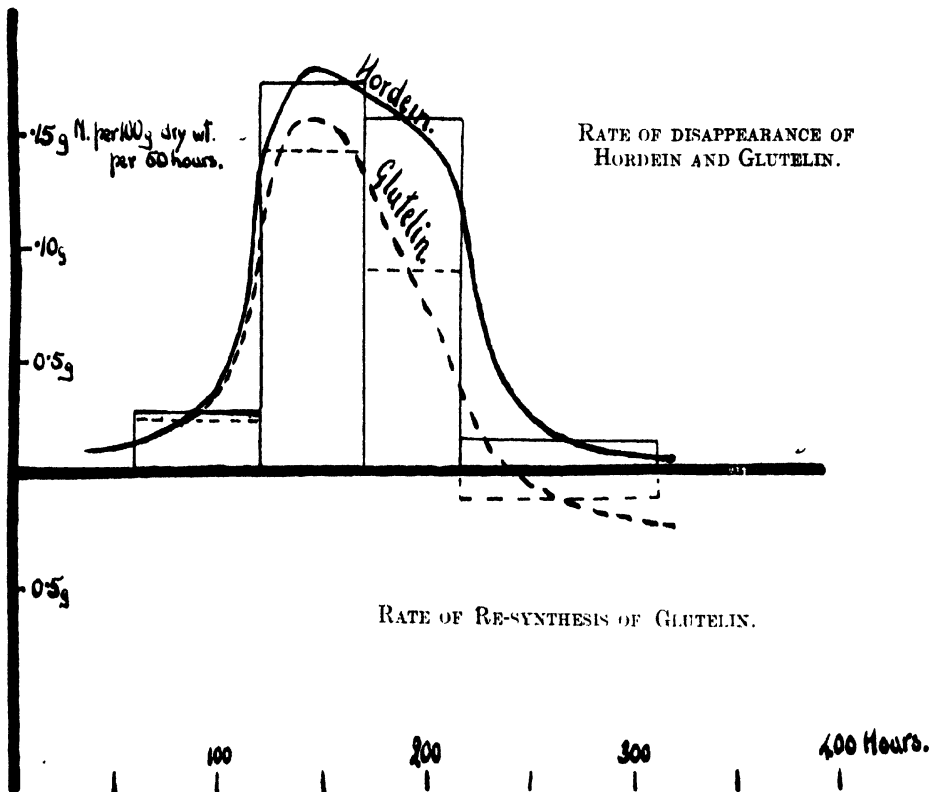
and purine bases. There is thus probably re-synthesis of glutelin in the rootlets and probably, by analogy, in the rest of the embryo also. This offers an explanation of the falling off in the apparent rate of breakdown of glutelin. Chibnall (6) has shown that the proteins of vegetative tissues are glutelins, so that such a re-synthesis is likely. Brown's (3) determinations of the rate of transport of nitrogen from the endosperm to the embryo during malting show that the rate did not fall off much, if at all, during the later stages on the floor. This also would suggest that the equilibrium shown by the analyses is a dynamic one.

It is possible to explain the apparent falling off, in the third stage, of the rate of hydrolysis of hordein in the same way as due to masking by re-synthesis of hordein in the embryo, but this suggestion is very hypothetical. There is no evidence, so far as I am aware, of the occurrence of alcohol-soluble proteins in any of the cereals outside of the endosperm and

husk. They have indeed been considered as characteristic reserves of these grains, so that direct evidence must be obtained before this suggestion can be accepted.

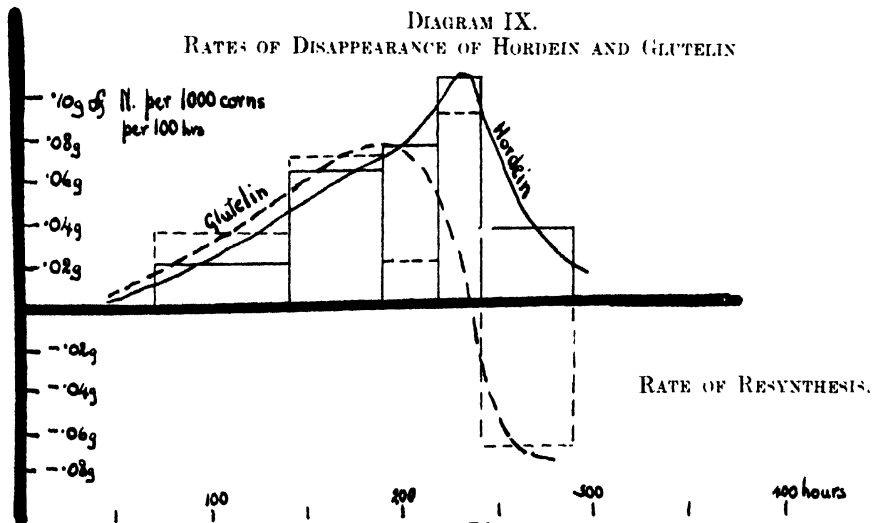
The falling off in rate is not accounted for by (a) cessation of active breakdown, or (b) lack or shortage of hordein to attack. Brown's results mentioned above are against (a). Also it was found that water added to a sample in Experiment II, at about 200 hours produced greatly increased growth but no differences from the main bulk in the nitrogen distribution between the different proteins. For this experiment about a kilo of grain was sprinkled plentifully with water, enclosed in a muslin bag as in stocking malting and buried in the "piece." At the close of germination the plumule projected well beyond the length of the corn and the rootlets were more numerous and longer. The very small effect produced on the amounts of the different nitrogenous bodies is illustrated in the following table (Table I, p. 331).

DIAGRAM VIII.



EXPT. I.

DIAGRAM IX.
RATES OF DISAPPEARANCE OF HORDEIN AND GLUTELIN



EXPT. II.

TABLE 18.

	<i>Nitrogen per 1,000 Corns in the form of</i>						
	Salt-sol.	Hordein.	Glutelin.	Albumin.	Globulin.	Proteose.	Non-prot.
290 hours germination without extra water ...	·350	·095	·192	·051	·054	·044	·207
290 hours germination with extra water ...	·357	·096	·187	·068	·056	·041	·196

Time is reckoned in all cases from the commencement of steeping.

Against objection (*b*) that there was shortage of hordein to attack, it was found in Experiment I that the amount of hordein not broken down at the end was equivalent to 16.9 per cent. of the total nitrogen while the total nitrogen of the husk at this stage was only 13.9 per cent. of that of the entire grain, so that all of the remaining hordein could not have been protected from attack in the husk.

Since the other explanations of the falling off in the rate of breakdown of hordein fail, it may be assumed for the moment that hordein is re-synthesised in the embryo. It is then possible to produce a general scheme for the protein distribution in any organ of the barley plant during its development.

Meristematic tissue (*i.e.*, that capable of active cell division) is assumed to contain only albumin and globulin. Osborne (?) states that albumin and globulin are the proteins of the embryo of ungerminated wheat grain and that gliadin and glutelin are not present. If this is assumed to be true of the barley embryo then glutelin is synthesised in the developing embryo behind the meristematic regions which contain albumin and globulin. The possibility is now considered that hordein may later be built up in the glutelin containing cells probably only as a temporary stage behind the growing point. This scheme has the advantage that it is also capable of explaining the sequence in which I found the proteins to develop in grain as it was growing in the field (these results will be published later).

Experiment III.

The period of rapid attack here sets in earlier than in the other experiments (Diagram X p. 332) and the rise in salt-soluble nitrogen is shorter and steeper. This is

related to the high temperature at this stage and was correlated with rapid growth of rootlets. The graph of the rates of disappearance of hordein and glutelin (Diagram XI p. 332) shows the rapid breakdown, and after this very little appears to happen. The apparent slight alternate synthesis and breakdown of glutelin afterwards may be due to the fluctuations in temperature or to sampling error. There is no marked rise in the glutelin at the end. The rapid growth of the embryo at the beginning may account for the longer period in which there is a state approaching equilibrium, since the rate of synthesis would more rapidly overtake the rate of breakdown. The high respiration rate (deduced from the changes in 1,000 corn weight) and rapid temperature rise shows continued metabolic activity, and is evidence against the sudden cessation of protein breakdown which is the superficial suggestion from the analyses.

Changes in the Salt-soluble Constituents.

These changes are graphed for Experiments I and II in Diagrams XII and XIII (p. 333.) Both peptases and tryptases are present in the germinating barley [Lundin (?).]. Tryptic action is, however, dominant, since nearly the whole of the rise takes place in the non-protein nitrogen.

In Experiment III (Diagram XIV p. 334) the albumin and globulin are seen to be higher in this barley than in the other two barleys, and they increase more through the malting period. The proteose fraction is consistently smaller than in the English barleys, and the rise in non-protein nitrogen is not so marked.

The smaller magnitude of the changes involved, which can be clearly seen from Diagram V (p. 328), indicates that the apparent proteolytic activity is less in this barley; but the real reason may be that the

DIAGRAM X.
EXPT. III.—Changes in Main Fractions during Malting. Chilian Barley.

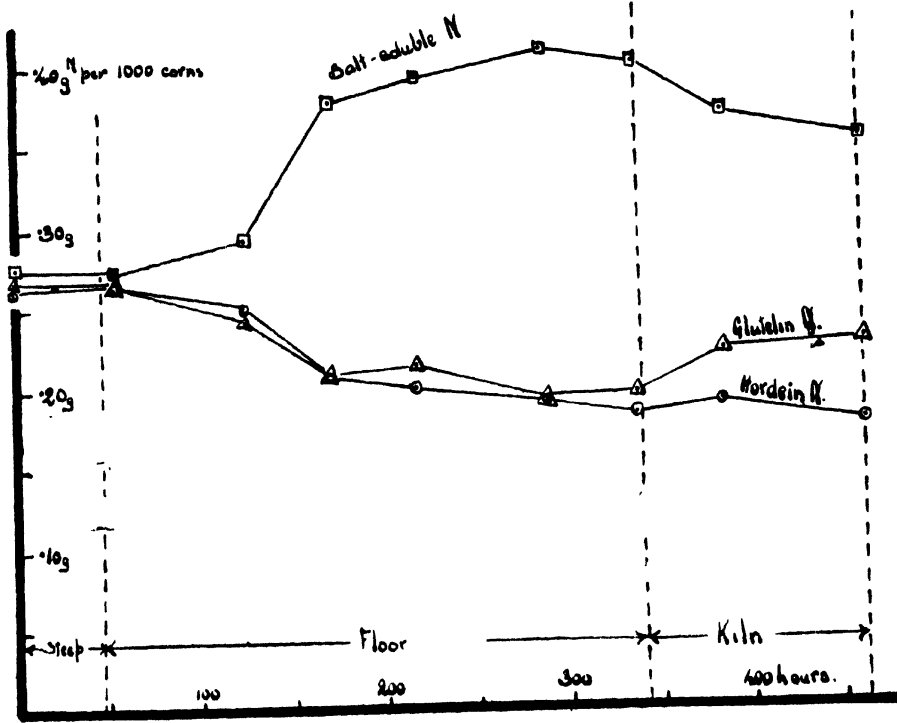


DIAGRAM XI.
RATES OF BREAKDOWN OF HORDEIN AND GLUTELIN.

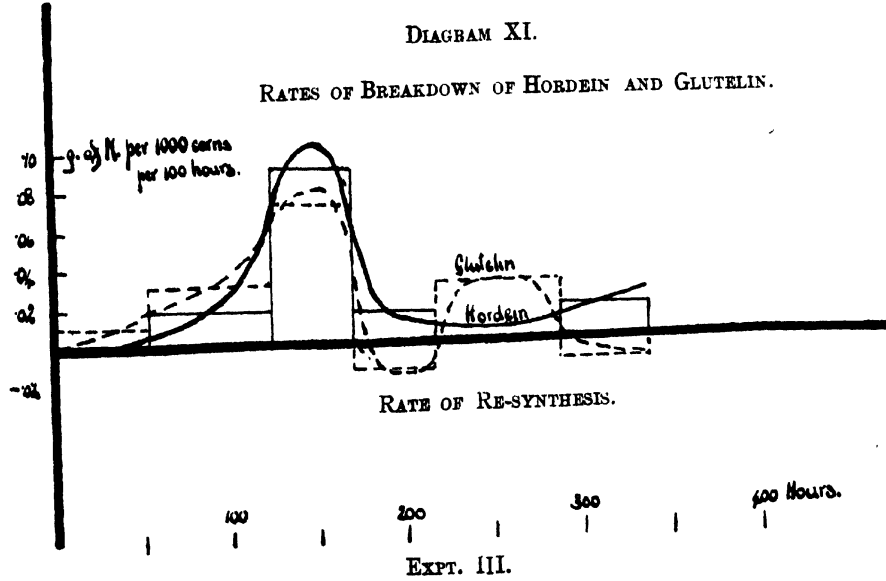


DIAGRAM XII.

EXPT. I.—Changes in the Salt-soluble Constituents during Malting.

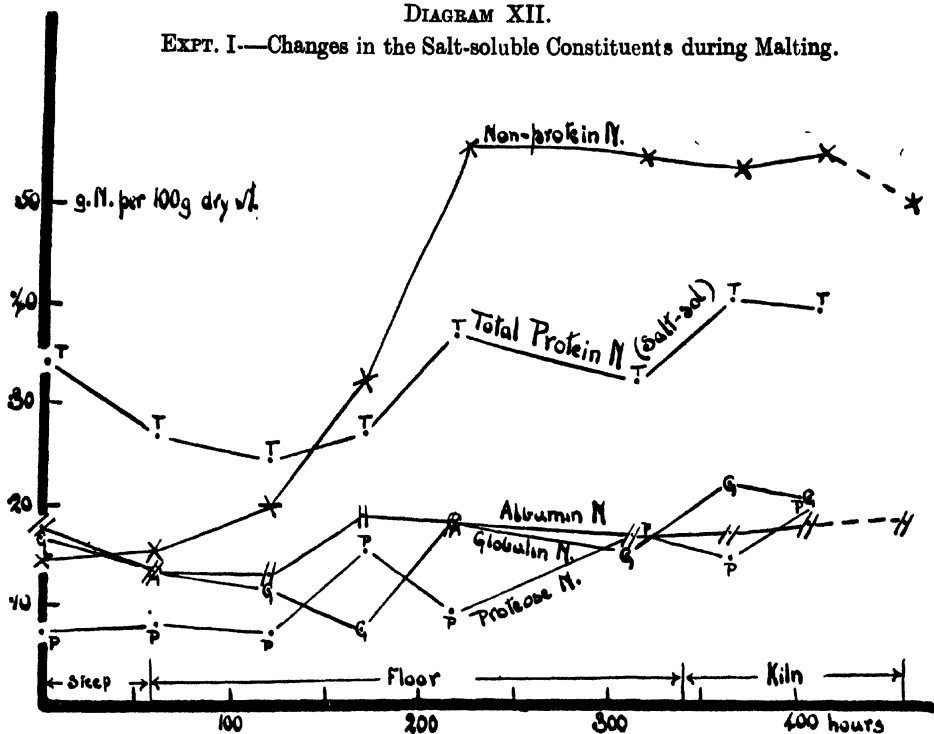


DIAGRAM XIII.

EXPT. II.—Changes in the Salt-soluble Constituents during Malting.

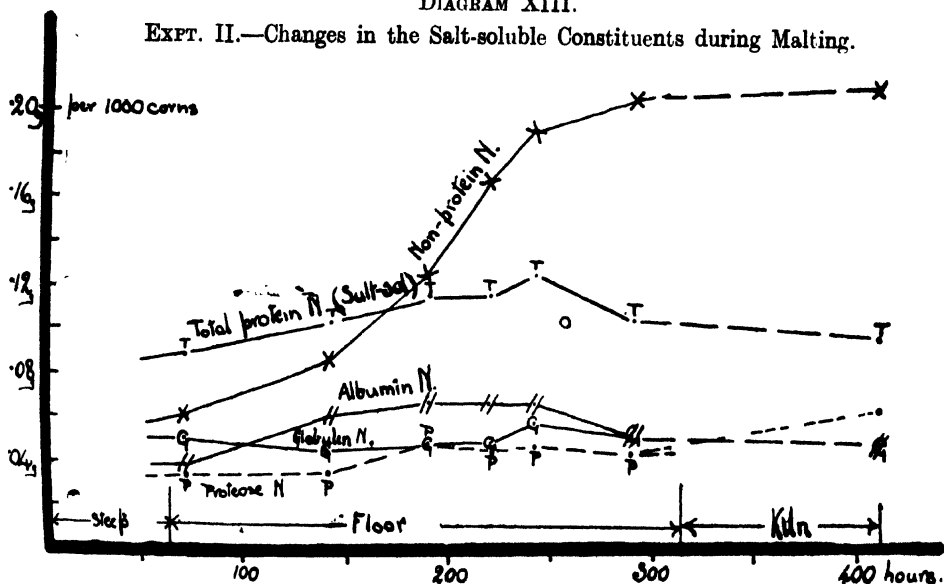
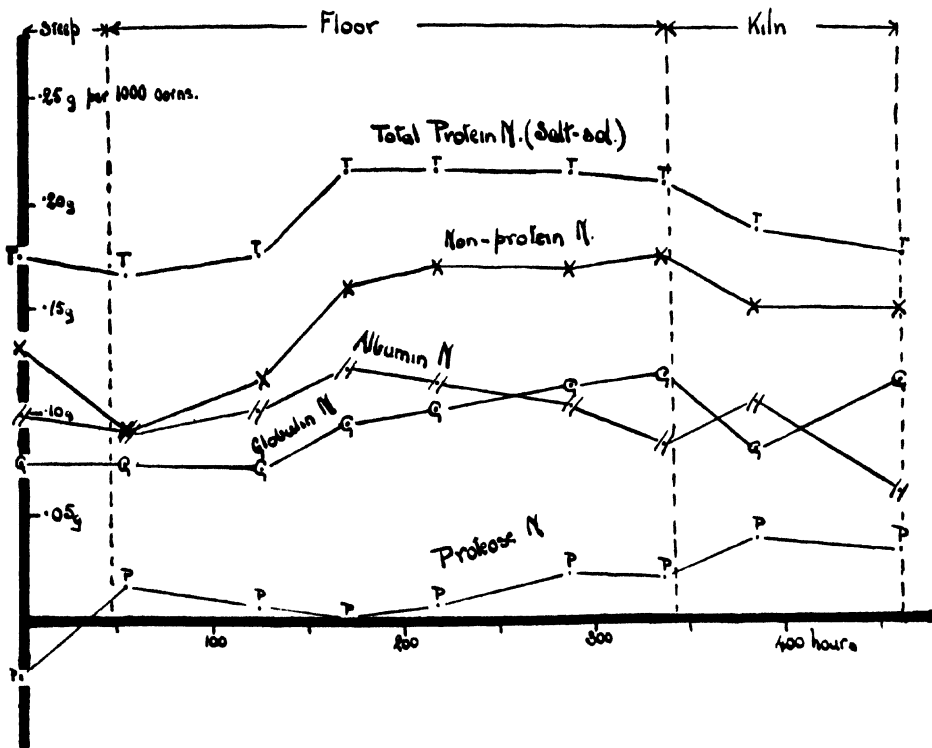


DIAGRAM XIV.

EXPT. III.—Changes in the Salt-soluble Constituents during Malting. Chilean Barley.



quicker development of the embryo allowed it to over take the production of breakdown products at an earlier stage.

It may be noted here that much of the "non-protein" nitrogen consists of organic bases such as betaine, choline, allantoin and hordenine. These must arise (in an as yet obscure manner) directly or indirectly from the breakdown of proteins. Their formation makes an estimation of the amino-acids, not a true measure of the amount of proteolytic activity.

The amount of ammonia was followed in Experiment I by the method of Foreman⁽⁹⁾. It increases somewhat during malting, but remains a very small proportion of the total nitrogen, as Windisch and Kolbach⁽¹⁰⁾ found. Foreman's method indicated the absence of ammonia from the barley itself, which is contrary to the findings of other workers.

Changes on the Kiln.

Experiments I and III give most detailed information about this. The most striking thing is that the changes are so small. The apparent change at the end of Experiment I is due to the malt being analysed alone, instead of the malt with its correct complement of rootlets, as has been done in the other two experiments. It is not certain that the small fluctuations which are recorded are significant. It might be expected that when the temperature approached 140° F. denaturation of the albumin would take place. This does not occur to any great extent, and it must be assumed that the drying is so gradual that the tissues have reached a degree of dryness at which the albumin is stable before a sufficiently elevated temperature is reached to cause coagulation. The malts produced were all pale malts. If kilned at a higher temperature, more

serious changes would probably have taken place. Luers and Nishimura ⁽¹¹⁾ also conclude that there is little change in the nitrogenous constituents on kilning pale malts.

In Experiment III in the early stages on the kiln there is a decrease in total protein in the salt solution (*i.e.*, albumin + globulin) and in the non-protein nitrogen, while there is a small increase in proteose. The net result is a reduction of the salt-soluble nitrogen, while the difference appears as glutelin nitrogen.

Effect of Varying Conditions during Flooring on the Composition of the Final Malts.

Experiment II was also made as an experiment on the effect of variation of conditions on the malts produced. The course of the main piece followed normal malting practice, but experimental portions were enclosed in stockings and treated in various ways. They were as far as possible buried in the "piece" to which they belonged.

The following table gives the results of analyses of the final malts (devoid of root-lets).

instance, by accumulation of CO₂ or serious attack by bacteria or fungi) more marked effects would be shown.

If the value obtained for the salt-soluble nitrogen of the stocking malt for 10½ days is assumed to be slightly too low and the glutelin value correspondingly too high, then comparing the stocking malts for 8½ days, 10½ days and 12½ days flooring, the general tendency seems to be for the salt-soluble, glutelin and non-protein nitrogen to increase slightly with time and for hordein to decrease slightly. This indicates that the general slope of the curves during the third stage is continued to 12½ days. Kilning is regarded as simply fixing the differences produced. Compared with the above three malts, that receiving less water (48 hour steep), and that receiving more water (from extra sprinkling at 6 days), are both most closely comparable with the malt of the same flooring period (10½ days), and this points to the small effect of the amount of water (within limits) during flooring on the distribution of the nitrogen compounds.

TABLE 2.

Effect of Varied Conditions of Treatment on the Composition of Malts.

	N. per 100 grains. dry weight in the form of—							
	Extract.	Salt-sol	Hordein.	Glutelin.	Albumin.	Globulin	Proteose etc.	Non- Protein
Normal floor malt, 60 hours steep. 10½ days on floor	100·3	·891	·220	·397	·189	·072	·067	·552
Stocking Malt, 48 hour steep ...	100·6	·844	·231	·396	·182	·087	·091	·436
Stocking Malt, 8½ days on floor ...	98·5	·840	·247	·357	·119	·117	·125	·425
Stocking Malt, 10½ days on floor ...	99·0	·805	·244	·381	·153	·090	·068	·475
Stocking Malt, 12½ days on floor ...	99·6	·887	·207	·372	·091	·217	·065	·518
Stocking Malt, with extra water at 6 days	99·9	·853	·219	·377	·152	·181	·112	·416

I wish to thank Mr. F. E. Day, who determined the extracts.

The idea of a balance between the downgrade processes in the endosperm and the upgrade processes in the embryo explains the smallness of the variations which can be seen among these samples. At the same time, such a theory suggests that if the growth of the embryo is seriously checked (as, for

Comparing the floor malt with the stocking malts the former is seen to correspond most closely with the 12½ day stocking malt which suggests that in the stocking the changes are retarded. These indications from a single experiment are not to be regarded as definite, and they await confirmation. The low extract from the malt receiving 8½ days on the floor shows that modification

was not complete while the differences between the others are not marked.

It seems necessary that the next step in the study should be one with experimental maltings in which all the many factors are controlled. Such experiments would be necessary to understand the effect on the malt and wort composition of various factors, such as variety, moisture content, aeration and temperature at various stages. Such work would be of far greater value if the effect of these conditions on the carbohydrates and enzymes were followed at the same time.

RESULTS OF OTHER WORKERS.

Loibl⁽¹²⁾ and Schjerning⁽¹³⁾ have followed the changes during malting of those nitrogen compounds in barley which are extracted by water.

Loibl's estimations of the total soluble and permanently soluble nitrogen confirm the three stages in the attack. The "total soluble nitrogen" probably consists of the albumin, some globulin (owing to the salts present), proteoses, peptones, etc., amino-acids and simple bases. Albumin, part of the globulin, and some of the higher proteoses would be removed on boiling, leaving the remainder as "permanently soluble nitrogen." As stated in the First Report, the amount of globulin dissolved will vary with the amount of salts present and the proportion of grain to water.

Schjerning's results only show a rising period and an equilibrium stage. This is because he never took his second sample until the fourth day. As was stated in the First Report it is not easy to compare with mine the fractions obtained by his precipitation methods.

regarded the total alcohol-soluble nitrogen as hordein. His results also indicate the three stages of the attack on the hordein.

Moritz and Fuller⁽¹⁵⁾ have followed the changes in the amount of amino nitrogen (by titration methods) during malting. They found a rise, and then an equilibrium stage which set in at about the same time as in my third experiment.

POSSIBLE LOSS OF NITROGEN DURING MALTING.

It is well known that some nitrogenous matters are dissolved out during the steeping process, but apparently it has been claimed that there is also a loss subsequently by "respiration." H. van Laer⁽¹⁶⁾ states "parce qu'une certaine quantité de cet élément (N) est éliminé par la respiration—L'élimination de l'azote par respiration est particulièrement élevée quand la germination est forcée par l'élévation excessive de la température, ou des arrosages copieux." No specific reference to original work is given however.

It will be seen that when calculated as nitrogen per 1,000 corns (a constant basis) neither Experiment II nor III give any indication of such a loss of nitrogen, apart from the loss in steeping and a loss at the end of the kilning due to incomplete recovery of rootlets (Table 3, p. 336). Such small haphazard variations as are seen in the intervening period may safely be attributed to small sampling errors.

SUMMARY.

An examination of the amounts of the separate proteins in barley and in the corresponding malt suggests that it is chiefly hordein which has broken down to give salt-soluble constituents. Actually this

TABLE 3.

Total Nitrogen per 1,000 Corns (with rootlets).

				Barley	On Floor.						On Kiln.	
Expt. II	...	...	...	—	·635	·634	·631	·642	·627	·638	—	·622
Expt. III	...	...	...	·807	·795	·783	·788	·804	·791	—	·799	·780

Kraft⁽¹⁴⁾ has estimated the amount of hordein during a malting by direct alcoholic extraction and precipitation from this by copper hydroxide. His estimate of the nitrogen in this precipitate would be nearer the actual amount of hordein than if he had

study shows that as soon as active breakdown commences after steeping, the two insoluble proteins of the endosperm, hordein and glutelin, are broken down at about the same rate, to give salt-soluble products. Then the rate of disappearance of glutelin falls off,

Later the rate of disappearance of hordein becomes very small, and the amount of glutelin may increase slightly. At this stage it is kilned.

The falling off in the rate of disappearance of glutelin and the suggestion of a subsequent increase point to a resynthesis of this protein in the embryo. The possibility is suggested that the falling off in rate of disappearance of hordein may similarly be accounted for by resynthesis in the embryo.

The breakdown of hordein and of glutelin gives rise chiefly to the simpler nitrogen compounds comprised in the term "non-protein" nitrogen. Albumin, globulin and proteose increase somewhat, but not very markedly.

In the Chilian barley studied, the albumin and globulin are larger in amount and increase more during malting than in the English barleys. The amount of proteose is less, and the apparent proteolytic activity during malting is not so marked.

The changes in the nitrogen compounds on the kiln when making pale malts are very slight.

Experiments with differing treatment of the same barley on the floor yielded malts the nitrogen distributions of which were very similar. This is accounted for by the tendency to reach, towards the end of the flooring period, a state of balance between breakdown of proteins in the endosperm and resynthesis in the embryo. This equilibrium is not easily disturbed (that is if the growth of the germ is not seriously checked).

There is no evidence in my experiments of any loss of nitrogen during the flooring period (apart from the loss in steep).

I am very grateful to Mr. A. C. Chibnall for his supervision during this work, and to Mr. W. B. Paterson, of Messrs. J. W. Green Ltd., Luton, for samples during malting.

Rothamsted Experimental Station,
Harpenden.

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APPENDIX.

ANALYSES OF BARLEYS DURING MALTING AND KILNING.

TABLE 4. *Experiment I.*
Barley—Garton's Improved.

Nitrogen grm. per 100 grms. dry weight, including rootlets.									
	Total Nitrogen	Salt Soluble.	Hordein	Glutelin	Albumin	Non-protein.	Total Protein.	Globulin	Proteose
0 hours ...	1.703	.563	.631	.509	.186	.130	.345	.159	.093
60 " ...	1.740	.502	.632	.606	.132	.152	.266	.134	.079
120 " ...	1.688	.508	.601	.579	.129	.195	.243	.114	.072
170 " ...	1.611	.743	.430	.438	.190	.318	.266	.076	.155
216 " ...	1.667	1.025	.286	.356	.179	.549	.366	.187	.062
312 " ...	1.662	1.031	.253	.378	.171	.532	.322	.151	.170
364 " ...	1.689	1.072	.270	.347	.176	.525	.399	.223	.150
406 " ...	1.684	1.048	.261	.375	.183	.546	.393	.210	.198
*456 " ...	1.597	0.935	.269	.393	.184	.507			

* Finished malt without rootlets. Steep 60 hours. Loaded on kiln at 340 hours.

TABLE 5. *Experiment II.*
English 2-rowed Barley.

	<i>N per 1,000 corns in the form of—</i>								
	1,000 corn wts.	Total Nitrogen	Salt Sol.	Hordein	Glutelin	Albumin	Non- protein.	Total Protein.	Globulin Protease
70 hours ...	42·9	·635	·185	·206	·245	·039	·062	·090	·051 ·035
141 „ ...	42·2	·634	·223	·191	·220	·060	·086	·103	·044 ·035
189 „ ...	42·6	·631	·286	·160	·186	·067	·125	·116	·049 ·049
218 „ ...	41·7	·642	·324	·138	·180	·067	·167	·115	·048 ·045
241 „ ...	40·7	·626	·356	·113	·159	·067	·191	·125	·058 ·048
290 „ ...	40·4	·638	·350	·095	·192	·051	·207	·105	·054 ·044
*410 „ ...	38·3	·622	·367	·075	·182	·048	·208	·096	·048 ·063

Roots included in all cases. *Finished Malt. Steep 60 hours. Loaded on kiln at 314 hours.

TABLE 6. *Experiment III.*
Chilean 6-rowed Barley.

	<i>Nitrogen per 1,000 corns in the form of—</i>								
	1,000 corn. wts.	Total Nitrogen	Salt Sol.	Hordein	Glutelin	Albumin	Non- protein.	Total Protein.	Globulin Protease
0 hours ...	45·95	·807	·276	·261	·267	·099	·132	·174	·076 ·025
53 „ ...	45·05	·795	·272	·262	·262	·089	·091	·164	·074 ·017
124 „ ...	44·50	·783	·290	·249	·240	·099	·114	·171	·071 ·008
170 „ ...	43·73	·788	·375	·207	·207	·120	·159	·213	·093 ·003
217 „ ...	44·18	·804	·393	·199	·213	·111	·168	·212	·101 ·009
288 „ ...	43·41	·791	·410	·192	·190	·102	·167	·212	·111 ·023
337 „ ...	42·91	·779	·402	·183	·195	·085	·173	·207	·117 ·021
384 „ ...	42·67	·782	·370	·191	·222	·104	·150	·185	·081 ·040
*460 „ ...	41·43	·758	·354	·176	·228	·060	·147	·174	·114 ·033

Rootlets included in all cases. *Finished Malt. Steep 53 hours. Loaded on kiln at 340 hours.

INSTITUTE OF BREWING RESEARCH SCHEME.

FOURTH REPORT ON BARLEY PROTEINS.

THE PROTEINS OF BARLEY DURING DEVELOPMENT AND STORAGE AND IN THE MATURE GRAIN.*

THE COMPOSITION AND QUANTITATIVE ESTIMATION OF THE BARLEY PROTEINS.—III.

BY L. R. BISHOP, M.A., Ph.D.

In my first report I gave the results of estimations—by a method proposed there—of the amounts of proteins in a number of Plumage-Archer barley samples. This particular set showed a very definite and regular relationship between the amounts of the different proteins, and suggested a similar type of relationship for other varieties. Since that time, this suggestion has been extensively studied, and tested by methods which have been improved in detail.

It will be seen later that the present results place the suggestion on a wider and firmer basis. A very pertinent point then emerges, if these regularities exist, how do they arise? In order to study this point, attention was directed to the development of the barley grain on the plant, since it is during this period that the greater part of the protein formation might be expected to take place. As the result of studies of samples of developing grain, taken during the summers of 1928 and 1929, and of a number of other samples this report presents an outline of the changes in the amounts of protein during development, and also of the subsequent maturation changes. Studies are also given of the proteins of mature grain of different varieties, and these suggest interesting varietal differences and similarities.

As the importance of the nitrogen compounds in practice becomes clearer, so the necessity becomes greater for a sound understanding of the behaviour of barley proteins, and it was to this end that the research was directed. This Report is chiefly a presentation of experimental data, the theoretical considerations arising from them will be dealt with in a later paper.

SECTION I.

CHANGES OF THE PROTEINS DURING THE DEVELOPMENT AND STORAGE OF BARLEY GRAIN.

A preliminary development experiment was carried out in the summer of 1928, and a more detailed experiment in the summer of 1929. The results are regarded as giving valuable confirmation of the regularities indicated by the studies of protein amounts in mature grain.

EXPERIMENTAL METHODS.

The variety chosen for development study in 1928 was Standwell, and in 1929, Plumage-Archer. The chosen plot of barley on the Rothamsted Experimental Farm was watched until the first day on which anthers emerged from the developing grain. On this day several thousand of the ears, with anthers showing, were then marked by loosely tying red wool below the ears (method of Miss Brenchley, *Ann. Bot.*, 1912, 903). The assistance in this of a number of members of the Rothamsted staff is gratefully acknowledged. These marked ears were all of the same physiological age, and samples from these ears may be regarded as showing the development of a single ear or grain.

At intervals of a few days samples of several hundreds of these ears were taken at random over the whole plot, and in 1929 duplicate samples were taken to estimate the combined sampling and analytical errors. The results show that these were small.

The samples were rapidly taken to the laboratory. The fresh weight of a hundred ears was determined. The awns were cut off, and the grain separated from the ears.

*NOTE. - With the consent of the Research Fund Committee part of the data in this Report was incorporated in a Thesis presented to the University of Cambridge for the degree of Ph.D. A copy of this thesis was deposited in the University Library on 23rd March, 1929.

Blind corns were removed, and the thousand corn weight was determined in duplicate. The grain was then dried for 1 hr. at 40° C. in a vacuum oven. It was then removed, and put several times through a Wiley mill without a sieve, so that every grain was cut across by the knives. This greatly hastened drying, which was continued in the vacuum oven until the material was dry (*circa* 9 per cent. moisture). In the second season the drying arrangements were more elaborate. A higher vacuum was obtained and a current of air from a fine inlet swept through the drying material. The results indicate that enzyme action in the second set was checked before much change took place, but probably the arrangements in the first year were insufficient to do this entirely. The drying to 9 per cent. is necessary to check enzyme action, and to ensure sufficient and comparable fineness of grinding.

The dried material was carefully ground very fine, in a coffee mill (grinding twice), and then reground in a Wiley mill with a half mm. sieve.

The shortened form of extraction was employed (this *Journ.*, 1929, 316), but in the second season total protein in the salt extract was also estimated (p. 321, *ibid.*)

Since the amounts of carbohydrate and of nitrogen change rapidly, the grain itself is the only convenient unit as a basis for calculation. Consequently, results are given as weights of nitrogen per thousand corns and this unit is retained throughout the paper.

In 1929 the development of the proteins was followed also by cytological studies. Constant thickness microtome sections were cut of the grain from each sampling. These were stained by Millon's reagent and iodine, under constant conditions. Millon staining was made on:

- (1) Sections direct (giving salt-soluble proteins, hordein and glutelin.)
- (2) After salt extraction (giving hordein and glutelin), and
- (3) After salt and alcohol extraction giving glutelin alone.

There is no direct method of staining individual proteins, so this technique was devised to localise the position of the proteins in the grain.

RESULTS.

The results for the two years are given as amounts per thousand corns in Tables I. and II., and in Diagrams I., II. and IV.

TABLE I.
Development of Proteins in Standwell Barley.
Anthers emerged July 10th, 1928 = 0 days.

Age in days.	Grm. of Nitrogen per 1,000 corns.			
	Total.	Salt-Sol.	Hordein.	Glutelin.
7	0.421	0.216	0.089	0.116
10	0.509	0.240	0.137	0.132
14	0.669	0.272	0.218	0.179
18	0.757	0.294	0.272	0.194
24	0.821	0.298	0.296	0.227
30	0.901	0.318	0.337	0.246
	Total nitrogen per 100 grms.	Re-analysis after 20 months' storage.		
7	1.516	0.176	0.092	0.153
10	1.563	0.207	0.138	0.163
14	1.619	0.242	0.213	0.213
18	1.640	0.276	0.263	0.216
24	1.700	0.262	0.293	0.266
30	1.830	0.294	0.317	0.290

DISCUSSION.

The figures for both years show that the nitrogen and total dry matter in the grain increase regularly with time. The rate of entry is rapid at first and declines steadily. The nitrogen percentage remains approximately constant (see Diagram I.) which shows that nitrogen compounds and carbohydrates (which constitute the major part of the remainder) enter the grain in approximately constant relative proportions during the period studied.

In Diagram II. are given the curves for the amount of the proteins per thousand corns in developing Standwell grain. It is clear here and in developing Plumage-Archer (Diagram IV.,) that salt-soluble nitrogen is high at first, glutelin increases steadily throughout and hordein most rapidly in the later stages. By comparison of Diagram II., with that for mature grain (Diagram III.) it becomes clear also that the relationships seen in mature grain are the result of the developmental sequence common to the variety. Within each variety at

TABLE II.
Analyses of Development Samples Plumage-Archer.
After emergence, July 12th, 1929=0 days.

		Initial Moisture, % on dry	Final Dry Matter %	1,000 Corn Weight, grms.	Weights of Nitrogen in grm. per 1,000 Corns.					
					Total.	Salt Sol.	Total* Protein.	Non- Protein.†	Hordein.	Glutelin.
Sample I.	A	219·6	93·69	14·03	0·220	α 0·153	0·071	0·087	0·011	0·056
	3 days B	222·7	94·01	14·08	0·212	α 0·149	0·065	0·085	0·011	0·052
Sample II.	A	182·0	92·55	24·64	0·354	α 0·186 β 0·159	0·070 0·044	0·116 0·117	0·060 0·065	0·108 0·130
	7 days B	180·5	92·62	24·74	0·355	α 0·192 β 0·164	0·068 0·045	0·124 0·119	0·061 0·067	0·102 0·124
Sample III.	A	130·2	93·05	32·70	0·438	α 0·256 β 0·218 γ 0·194	0·144 0·102 0·083	0·115 0·115 0·111	0·093 0·102 0·109	0·089 0·118 0·135
	10 days B	138·0	93·30	33·15	0·460	α 0·262 β 0·252 γ 0·200	0·140 0·126 0·082	0·124 0·126 0·120	— 0·100 0·117	— 0·108 0·143
Sample IV.	A	102·2	91·64	39·29	0·543	α 0·235 β 0·215	0·113 0·091	0·122 0·121	0·158 0·158	0·150 0·170
	14 days B	104·2	92·25	39·41	0·554	α 0·253 β 0·206	0·129 0·087	0·124 0·118	0·162 0·174	0·139 0·174
Sample V.	A	100·2	93·09	42·34	0·614	α 0·253	0·135	0·119	0·204	0·157
	17 days B	99·00	93·20	42·51	0·605	α 0·250 β 0·230 γ 0·215	0·134 0·109 0·106	0·120 0·123 0·110	0·200 0·197 0·210	0·155 0·178 0·180
Sample VI.	A	85·80	92·84	44·36	0·644	α 0·247 β 0·246	0·129 —	0·117 —	— 0·221	— 0·177
	21 days B	87·42	92·56	45·35	0·668	α 0·253 β 0·229 γ 0·225	0·134 0·127 0·121	0·121 0·101 0·102	0·233 0·215 0·230	0·182 0·224 0·233
Sample VII.	A	48·09	92·39	46·00	0·688	α 0·226 β 0·231 γ 0·217	0·122 — 0·125	0·104 — 0·093	0·259 0·258 0·264	0·228 0·224 0·232

* Total Protein: total fully built up protein in salt extract.

† Non-Protein here: usual non-protein plus proteose.

any given nitrogen content there is a tendency for the proteins in developing grain to settle down to a very definite equilibrium. During development, synthesis does not keep pace with the rate of entry of nitrogen into the grain, hence maturation changes ensue.

The hordein curves of mature and developing grain are so closely similar that they may be regarded as identical. The salt-soluble

nitrogen is higher than in mature grain and the glutelin correspondingly lower. Subsequent analyses (20 months later) of the same samples showed that salt-soluble nitrogen and glutelin had also settled down to the values given by mature grain (see the second part of Table I. p. 337).

The same behaviour is shown by the 1929 set of Plumage-Archer samples. These were

rapidly dried and so, it is considered, retained in almost the state at which they existed at the moment of sampling. At the time of rapid entry of nitrogen a large proportion of the nitrogen was in the form of simple compounds (non-protein and proteose nitrogen) in which form the nitrogen enters the grain or is first synthesised. Synthetic

tively. Many successive analyses were made of the development samples after intervals of time; these are given in full for the B samples for salt-soluble and glutelin nitrogen in Diagram VI. (p. 343). The duplicate analyses of samples A and B are given in full in Table II., and it will be seen that these agree so closely that the combined sampling and

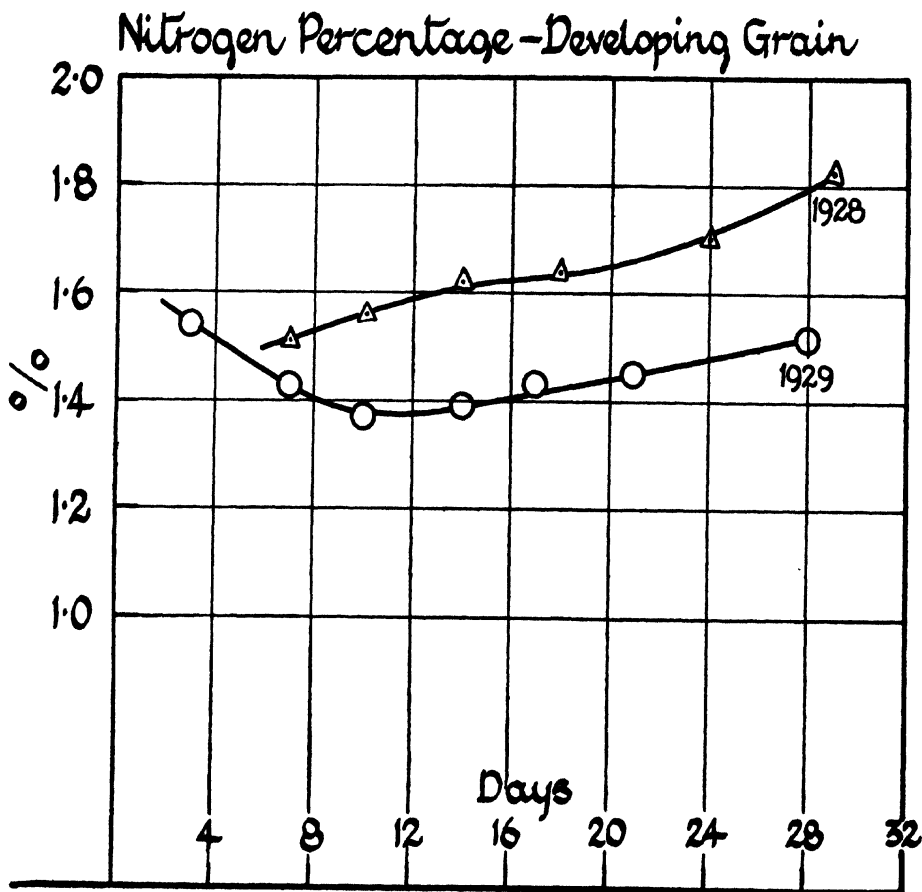


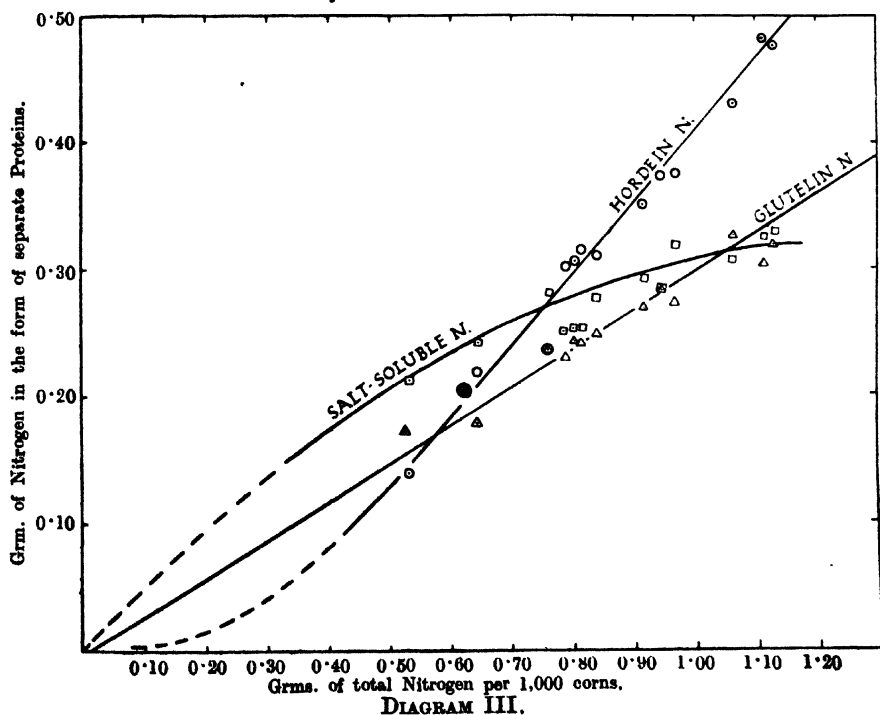
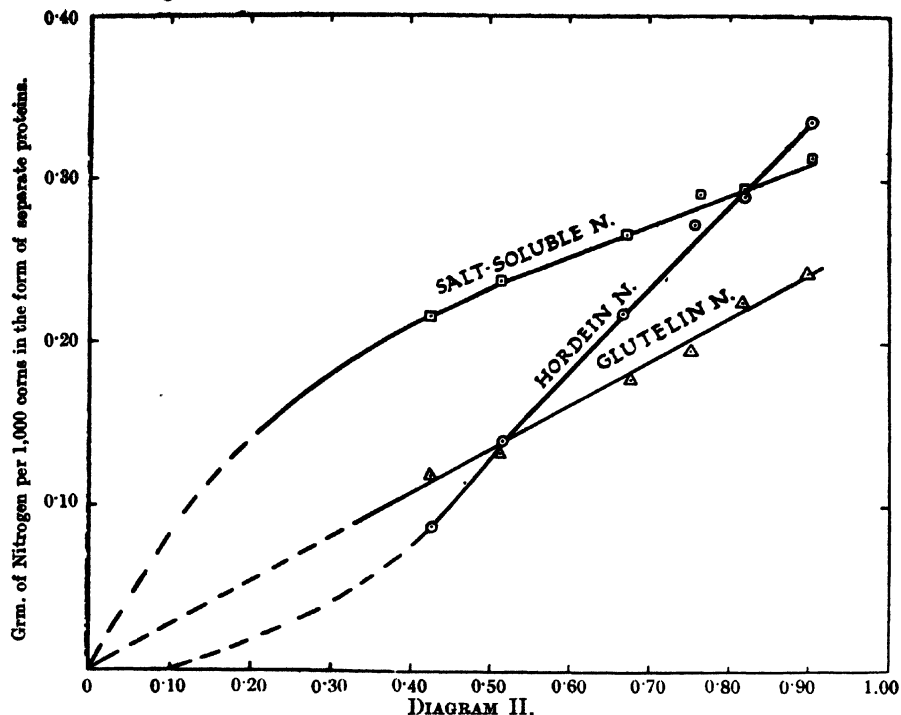
DIAGRAM I.

changes continued in the dried and ground grain, but at a very reduced rate, requiring months instead of hours to reach equilibrium. After several months storage the proportions approached those found in the mature grain of the same total nitrogen content per thousand corns. This can be seen on comparing Diagrams IV. and V. of the developing and mature grain, respec-

analytical errors are negligible and these conclusions are, therefore, sound.

In this table are given the successive analyses of each of the samples (α , β and γ). The first (α) is an analysis immediately after collection, the second (β) a re-analysis after several weeks and the third (γ) a re-analysis after several months.

Clearly the nitrogen in the grain settles



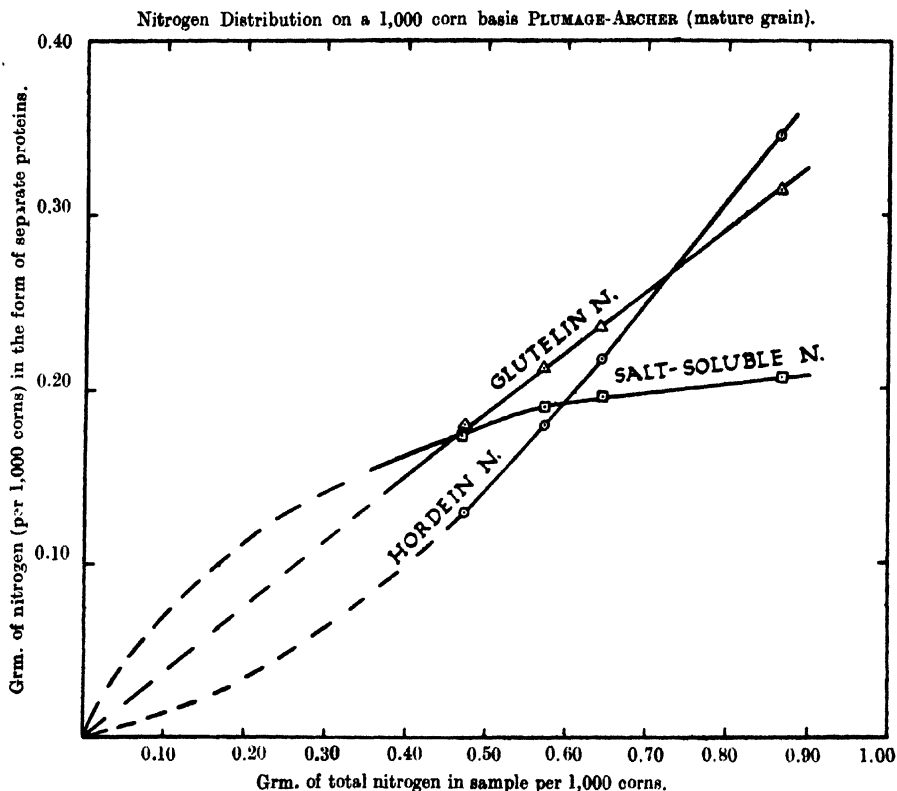
down to definite proportions regulated by the total nitrogen content, either in grain at any stage during development or in the final grain. Also it reaches the same final point whatever the moisture content (unless this is sufficient to cause germination). It also reaches the same equilibrium whether ground or unground.

Further, it can be seen that for a given total nitrogen content a different equilibrium is reached for Plumage-Archer than for Stand-

well has been stored for a very considerable period so that all the samples analysed have settled down to the final equilibrium. It is not safe to study the regularities in grain less than a year old.

SIGNIFICANCE OF THE MATURATION CHANGES.

The demonstration of such maturation changes naturally raises the question of the relation of these to the simultaneous maturation change noticed by the maltster—the increase in germinative power in grain stored



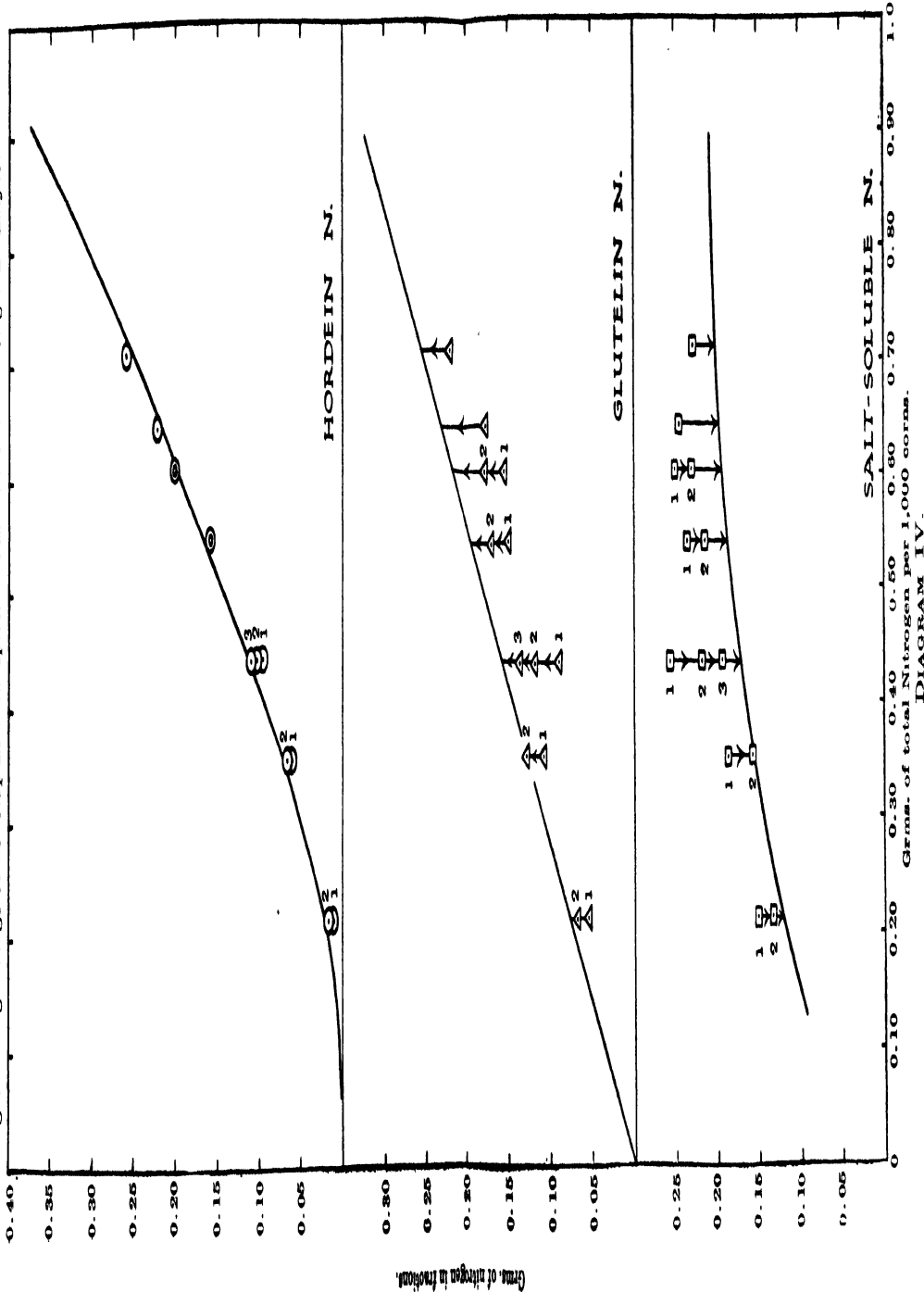
well. For instance, at 0.50 gm. of nitrogen per thousand corns the following amounts of nitrogen are found :—

	Salt-sol.	Hordein.	Glutelin.
Plumage-Archer ..	0.175	0.140	0.185
Standwell ..	0.24	0.13	0.13

The equilibrium is only reached in harvested grain after considerable storage periods, data showing this will be given later. The regularities which I have found in mature grain are only seen if this

after harvest. The two may be related, but I prefer to make no suggestion of relationship. The main part of the increase in germinative power is probably closely related to increase in oxygen permeability of the husk (see G. T. Harrington, *J. Agric. Res.*, 1923, 23, p. 79). Although there is probably also a change in the germ itself (W. Windisch, *Woch. Brau.*, 1905, 89). How far these changes are related to changes in the composition of the proteins is doubtful.

PLUMAGE, ARCHER.
Changes during storage of development samples. Curves from mature grain analyses.



Grams of total Nitrogen per 1,000 corns.
DIAGRAM IV.

THE BEST BASIS FOR COMPARISON.

The hordein value is always near its final value which suggests that the rate of formation is much more rapid than with glutelin. The former is, therefore, more reliable in comparing analyses.

Throughout this paper the considerations are based on weights of nitrogen per thousand corns since this is regarded as a better basis for calculation than amounts per hundred grams of dry weight. The thousand corn weights were all close together in the early samples studied so that the regularities were apparent on either basis. In the development samples and in samples of Standwell grain which were deliberately separated into grain of widely different thousand corn weights, it appears clear that the thousand corn weight is the better basis.

CYTOLOGICAL STUDIES.

It may be argued that the changes in the amount of the proteins during development may be due to successive development of different parts of the grain. For instance, if the salt-soluble nitrogen were chiefly in some part of the grain which developed early then this would account for its preponderance in the early stages. This suggestion is nullified, however, by cytological studies carried out in 1929. These show that not all, but the main part of the proteins is in the periphery of the endosperm and that all three, salt-soluble, hordein and glutelin are there together, and are not segregated in different organs.

The equilibrium between the proteins is therefore probably an equilibrium within the cell where they exist together. This is supported also by the fact that the equilibrium is reached in ground samples.

DIAGRAMMATIC SPACE MODEL.

The relations between development and maturity in high and low nitrogen barleys are shown diagrammatically in a space model. (See Diagram VI. p. 33).

In this diagram the heights represent weights per 1,000 corns of nitrogen in the form of the different proteins. These are superimposed so that the top surface measures the total nitrogen. The sides show development with time in high and low nitrogen barleys and the end represents and explains the resulting relation between mature samples of different nitrogen contents.

ANALOGY WITH THE PROTEINS OF WHEAT.

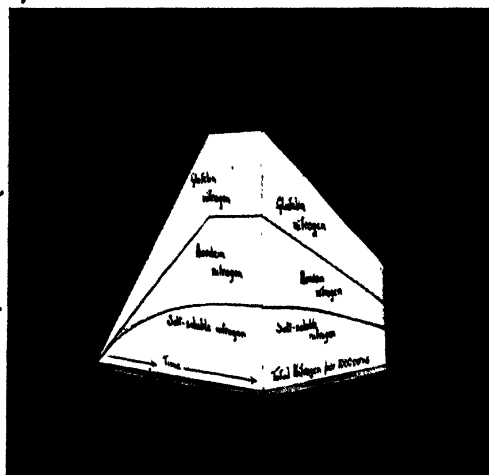
If the relationships suggested here for barley are valid then it might be expected that analogous regularities would be found in wheat. The available data for the proteins of wheat was therefore examined. H. E. Woodman and F. L. Engledow (*J. Agric. Sci.*, 1921, 563), used a method of estimation of the salt-soluble, alcohol-soluble and glutelin nitrogen which probably gave a good relative measure of the amounts of these proteins present, although only about 80 per cent. of the proteins was accounted for. When their results (per hundred ears) for the development of the proteins in wheat grain are plotted they give a set of curves very similar in type to the Plumage-Archer development curve (Diagram IV.). The proportion of salt-soluble nitrogen in their results is high at first and increases slowly only later in development. The glutelin increases steadily throughout. Gliadin (the alcohol-soluble protein of wheat, corresponding to hordein in barley) increases rapidly in the later stages. In the last analyses (after the yellow-ripe stage) salt-soluble nitrogen decreases in amount. The only difference from my results with barley is that in these analyses gliadin and not glutelin increases as a result of the decrease of salt-soluble nitrogen during maturation.

The analyses of developing wheat grain by C. E. Mangels and T. E. Stoa (*Cereal Chem.*, 1928, 385) are unfortunately given only as percentages and without a constant basis (such as a hundred ears or a thousand grains). Nevertheless they show the same general type of relationship.

The results of E. Grewe and C. H. Bailey (*Cereal Chem.*, 1927, 230) have also been studied. These authors analysed a number of samples of wheat flour by similar methods. When plotted the scatter of the points is greater than with the present barley analyses. Yet the same general type of relationship (as seen in Diagram VIII., First Report, this *Journ.*, 1928, 113) is clearly visible. The glutelin percentage remains constant, the gliadin proportion increases with increasing total nitrogen content (per 100 grams dry weight) with a corresponding decrease in the salt-soluble nitrogen. The salt-soluble nitrogen is a much smaller proportion of the whole in wheat than in barley.

Inter-relations of amounts of total nitrogen during development and at maturity.

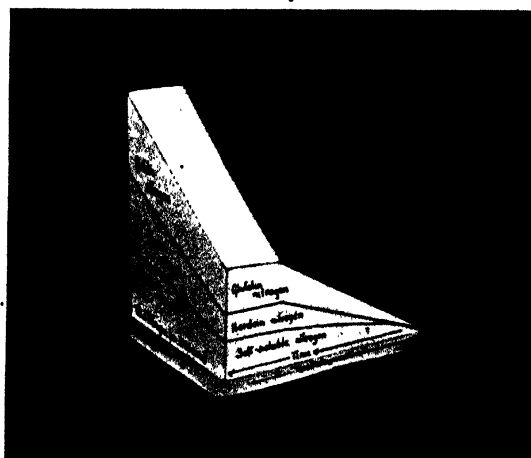
Development
High total nitrogen.



Relation between
samples of mature
grain.

Diagrammatic Space Model.

Mature
grain samples.



Development
Low total nitrogen.

DIAGRAM VI.

All this evidence suggests that the same type of relationship holds for wheat as for barley. This support gives broadness and soundness to the conclusions drawn from the analyses given here.

SECTION II.

VARIETAL DIFFERENCES AND SIMILARITIES.

METHODS.

The grain was dried at 38° C. to about 10 per cent. moisture; and it was then ground twice, as fine as possible, in a special coffee mill, and reground in the Wiley mill, using a $\frac{1}{2}$ mm. sieve. This ensures a fine grind which is comparable in different samples.

Estimations of moisture, thousand corn weight, total nitrogen, salt-soluble nitrogen,

and regular for each variety, or group of varieties. A. Szilvinyi (*Woch. Bran.*, 1930, 3) who has examined *one* sample of each of eight varieties by my method concludes that with these there is no regular relation between the quantities of each of the proteins and the total nitrogen. This is exactly what is to be expected in his results if varieties differ in their characteristic proportions of proteins.

It can be seen from Diagrams VII. and VIII. that, in the varieties Archer and F.112 (a race of *Hordeum hexastichum* raised by Dr. E. S. Beaven), here also the proteins are regular in amount within the variety and differ greatly between the two varieties. The values for Archer given in the First Report (this *Journ.*, 1928, 101) are slightly incorrect owing to differing fineness of grind.

TABLE III.

Analyses of Plumage-Archer Mature Grain.

Plumage-Archer Barley.	Weight of 1,000 Corns Dry. Grms.	Dry Matter %	Grms. of Nitrogen per 1,000 Corns.			
			Total.	Salt Ext.	Hordein.	Glut.
Porlock '25 mixed	40.97	87.72	0.474	0.171	0.128	0.175
Orwell '25 mixed	38.28	86.12	0.872	0.208	0.344	0.320
Louth '23 No. 15	42.42	87.52	0.578	0.189	0.178	0.211
Louth '23 No. 17	42.95	87.98	0.654	0.197	0.216	0.241

hordein nitrogen and glutelin nitrogen were made as described in the Second Report (this *Journ.*, 1929, 316).

RESULTS.

The results of analyses of mature Plumage-Archer, Standwell, Archer and F.112 barleys are given in Tables III., IV., V. and VI. respectively and in Diagrams III., V., VII. and VIII., in all cases as weights in grams per thousand corns.

DISCUSSION.

The curves for mature Standwell and Plumage-Archer grain given in Section I. are sufficient to demonstrate that with the mature grain the protein equilibrium is both regular within the variety and differs considerably in two different varieties, Plumage-Archer and Standwell. Diagrams III. and V.

Curves for other varieties given here and others still being studied also suggest that varieties differ in the equilibrium position for a given amount of total nitrogen, so that these proportions may be characteristic

By comparing the curves for the four varieties given here, it will be seen that the following statements are true for all the varieties studied. The salt-soluble nitrogen forms a greater proportion of the whole at low nitrogen contents than at the high, *i.e.*, it increases in amount less rapidly than the others. The change in proportion is regular with the increase in nitrogen content. On the other hand the hordein nitrogen is a low proportion of the whole at low total nitrogen contents and increases rapidly and regularly with increase of total nitrogen. The rise in hordein nitrogen percentage corresponds exactly to the fall in salt-soluble nitrogen percentage, so that the percentage of the remainder (glutelin) remains constant.

Varities differ, however, in the proportion of each protein at any given total nitrogen content. The easiest to consider is glutelin since the proportion remains constant within each variety for all total nitrogen contents. Thus Plumage-Archer has 36 per cent. of glutelin, F.112 has 41 per cent.,

TABLE IV.

Analyses of Mature Standwell Grain.

	Weights of nitrogen in grms. per 1,000 corns.				1,000 Corn weight. Grms.
	Total.	Salt. Sol.	Hordein.	Glutelin.	
Leegomery 1925 Medium	0·528	0·214	0·141	0·173	39·52
Leegomery 1927 Medium	0·621	0·204	0·208	0·209	37·52
Cannington 1928 Medium	0·641	0·242	0·220	0·179	39·44
Leegomery 1925 Large	0·757	0·232	0·237	0·238	49·91
C4 Medium	0·784	0·251	0·302	0·231	41·21
C2 Medium	0·800	0·252	0·305	0·243	40·55
C3 Medium	0·810	0·251	0·316	0·243	40·75
A4 Medium	0·835	0·278	0·309	0·248	43·76
Leegomery 1927 Large	0·912	0·292	0·350	0·270	48·51
C1 Medium	0·941	0·283	0·373	0·285	43·50
Cannington 1928 Large.. ..	0·964	0·318	0·373	0·273	50·28
C4 Large	1·060	0·305	0·430	0·325	50·13
C3 Large	1·113	0·327	0·481	0·305	50·83
C2 Large	1·123	0·328	0·474	0·321	50·23

Medium and large refer to the graded grain sizes. A4, C3, etc. refer to plots in the Rothamstead top dressing experiment of 1928.

TABLE V.

*Analyses of Mature Archer Barleys.**N.I.A.B. Samples.*

	Wt. of 1,000 Corns Dry. Grms.	Dry Matter. %	Grms. of Nitrogen per 1,000 corns.			
			Total.	Salt-sol.	Hordein.	Glutelin.
160 Mkt. Weighton, 1923	39·00	87·56	0·595	0·201	0·183	0·211
170 Norwich, 1923	39·16	88·94	0·718	0·220	0·257	0·241
167c Newton St. Faith, 1924	34·95	88·00	0·515	0·185	0·152	0·178
169c Newton St. Faith, 1924	34·69	88·02	0·476	0·174	0·132	0·170

and Standwell *circa* 30 per cent. Archer with 35 per cent. of glutelin, is not clearly distinguishable from Plumage-Archer. (See diagram IX, p. 348).

Hordein nitrogen can be measured much more accurately than the other proteins.

This is because in immature barley it reaches its equilibrium value much more quickly than the other proteins. The value is therefore not affected by immaturity. It is also not so much affected by the fineness of grinding of the sample.

The hordein value is therefore the most accurate and it would be preferable to use this for comparisons. It will be seen, however, that there is little, if any, difference in hordein content between the English two-rowed barleys; the differences here are largely differences in salt-soluble and glutelin nitrogen. The six-rowed barley F.112 differs markedly from the others in its hordein content.

The analyses of the F.112 and Standwell barleys have been repeated and the standard errors of the means for the proteins, when calculated as a percentage of the total nitrogen are given in Table VII. It will be seen that the standard error for hordein is even lower than that for total nitrogen, each determined by the usual Kjeldahl method.

The second analyses of the Standwell barleys were kindly carried out by Miss D.

TABLE VI.
Analyses of Mature F.112 Grain.

Barley Source.	Weights of Nitrogen in grms. per 1,000 corns.				1,000 corn weight, grms.
	Total.	Salt-Sol.	Hordein.	Glutelin.	
144 Small, 1926	0.288	0.112	0.055	0.121	20.80
Beaven's (1)	0.384	0.147	0.087	0.150	32.63
142c, 1927	0.443	0.161	0.102	0.180	33.57
Good Easter, 1928	0.456	0.176	0.090	0.190	37.24
141, 1926	0.459	0.168	0.100	0.191	34.65
195c, 1927	0.460	0.170	0.105	0.185	34.28
144 Medium, 1926	0.493	0.187	0.103	0.203	35.31
190c, 1927	0.532	0.171	0.138	0.220	36.06
Beaven's (3)	0.545	0.184	0.147	0.214	33.22
144, 1927	0.554	0.180	0.141	0.233	38.75
Beaven's (6)	0.623	0.188	0.181	0.254	31.88
Beaven's (5)	0.664	0.202	0.182	0.280	38.57

Glutelin thus appears as the best and simplest thing to compare in different varieties and the glutelin contents of the different varieties are plotted in Diagram IX (p. 348); they show marked differences between the different varieties.

ACCURACY OF THE ESTIMATIONS.

The differences of a few per cent. in the glutelin on which the arguments above are based, raise the question of the accuracy of the method, which if good enough, makes the differences significant and the conclusions based on these sound.

The accuracy has already been considered in the Second Report (this *Journ.* 1929, 316), but more detailed study is now necessary.

Marx, M.Sc., a year after my analyses. The mean difference in hordein nitrogen found is 0.1 per cent. of the total nitrogen. It therefore appears that the personal error in the estimations is negligible.

Values of three times the standard error are significant. The differences recorded

TABLE VII.
Variety F 112

STANDARD ERROR (S) OF MEANS OF ANALYSES.	
Thousand Corn Weight (Triplicates)	S = 0.10g = 0.52%
Dry Matter (Duplicates)	S = 0.045%
Total Nitrogen (Duplicates)	S = 0.006 = 0.4%
Salt Soluble Nitrogen (Dupl.)	S = 0.4% of total Nitrogen
Hordein Nitrogen (Dupl.)	S = 0.3% " " "
Glutelin (Dupl.)	S = 0.5% " " "
Standwell Hordein (Dupl.)	S = 0.2% " " "

Nitrogen Distribution on a 1,000 corn basis. ARCHER BARLEY (mature samples).

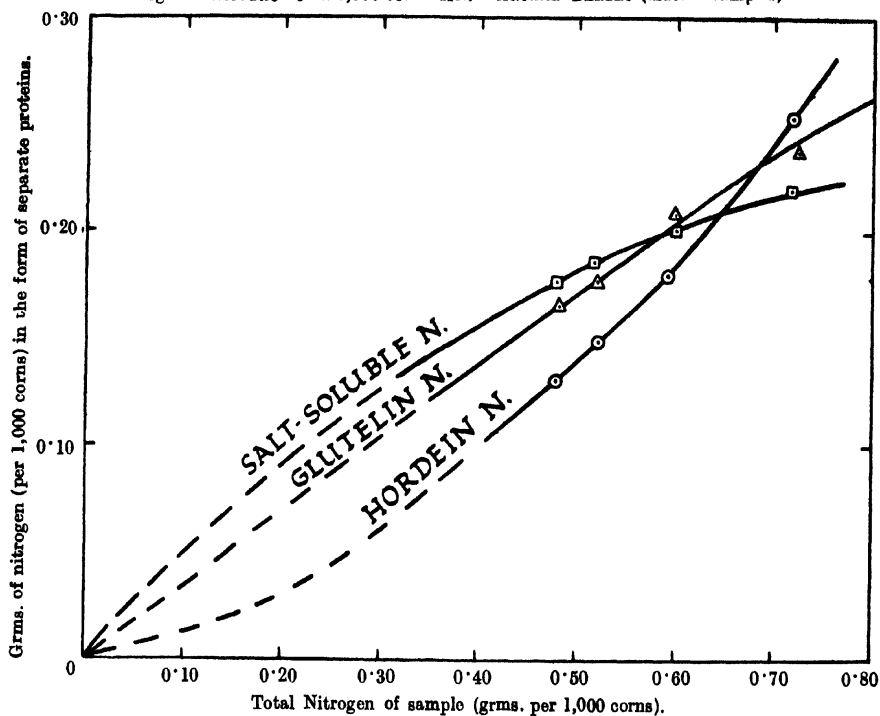


DIAGRAM VII.

F. 112. Analyses of mature grain.

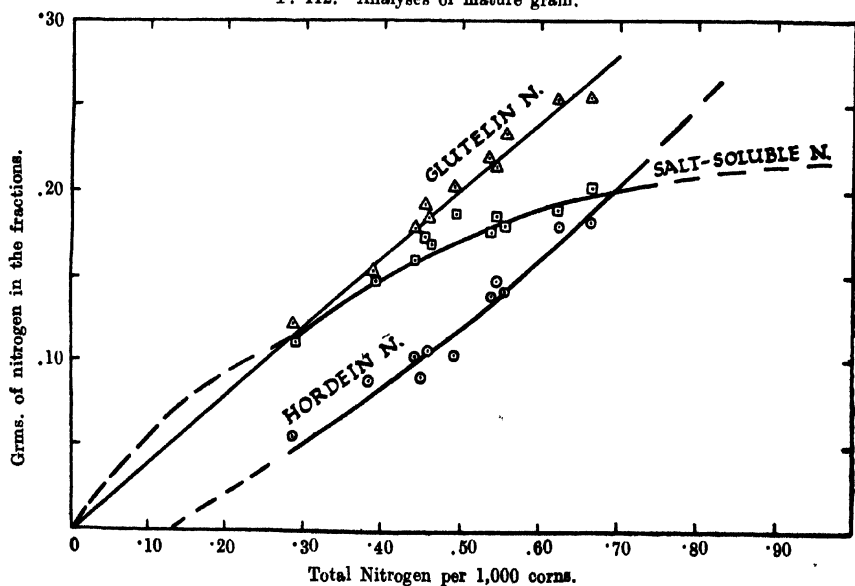


DIAGRAM VIII.

are hence manifestly real and therefore there are very significant differences between varieties in this respect.

The relationship between the quantities of the individual proteins and the total nitrogen is characteristic of the variety.—It does not necessarily follow that it will be possible to demonstrate significant differences between every pair of varieties.

HYBRIDIZATION.

The question of the mode of inheritance of these differences is obviously raised.

nitrogen, G=glutelin nitrogen and N is the total nitrogen per thousand corns.

The values of the factors (a, b, p, q, and x) are regarded as characteristic of the variety.

SUMMARY.

Within each separate variety the weights of the individual proteins are simple regular functions of the total nitrogen content per thousand corns. In each variety studied the percentage of salt-soluble nitrogen on total nitrogen decreases with increase of the total nitrogen. The hordein nitrogen per-

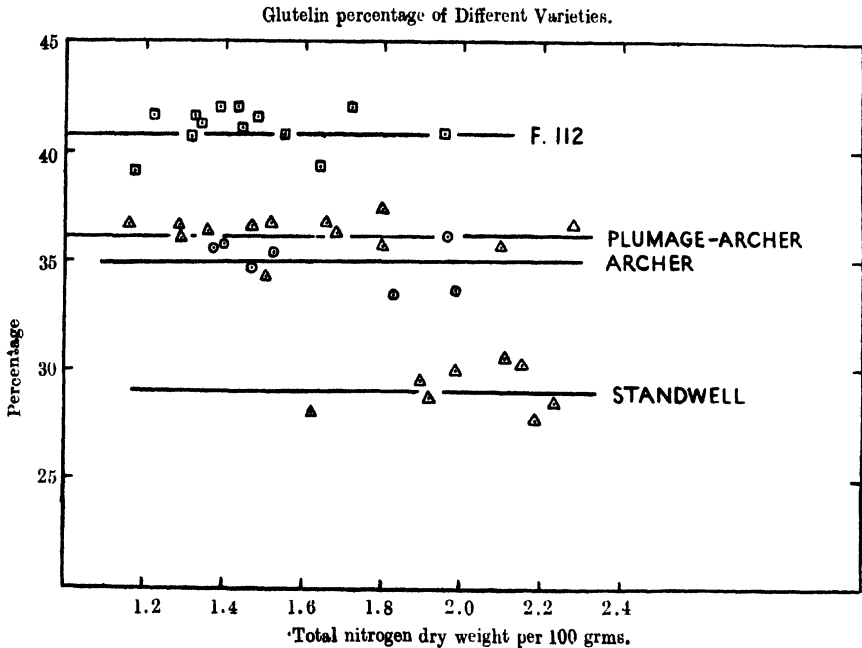


DIAGRAM IX.

What, for instance, is the relation of the protein proportions in Plumage-Archer to its parents Plumage and Archer? This aspect is at present under investigation.

MATHEMATICAL SUMMARY.

It is suggested that in mature grain of any one variety, or pure line, the protein proportions may be represented as follows in amounts of nitrogen per thousand corns :—

$$S = aN - bN^2$$

$$H = pN + qN^2$$

$$G = xN$$

Where S = salt-soluble nitrogen, H = hordein

percentage shows a corresponding increase so that the glutelin percentage remains constant throughout.

The curves for different varieties are therefore all similar in form, but they differ in actual magnitude. These differences are, in most of the cases studied, so much larger than the analytical errors that they are undoubtedly significant and are characteristic of the variety. *The relationship between the quantities of the individual proteins and the total nitrogen is characteristic of the variety.*

If they are allowed time to reach the natural equilibrium, exactly the same proportions of the proteins are found in samples of develop-

ing grain as in mature grain of the same total nitrogen content per thousand corns. However, when freshly taken, development samples and immature grain contain a larger proportion of simple compounds which have entered the grain but have not been synthesised to the equilibrium point. *Development of the proteins in the barley grain is essentially a synthesis, of the simple compounds which enter it, up to a definite equilibrium point controlled only by the total nitrogen content and the variety.*

Salt-soluble, hordein and glutelin nitrogen

are congregated chiefly, but not entirely, in the periphery of the endosperm and it is suggested that the regularity in the quantities of these proteins is due to a type of mass action equilibrium within the individual cell.

I gratefully acknowledge the following:— Help with the analyses from Miss D. Marx, M.Sc. and Mr. F. E. Day, B.Sc., F.I.C., samples of grain from Dr. E. S. Beaven and the National Institute of Agricultural Botany, and advice from Prof. A. C. Chibnall.

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INSTITUTE OF BREWING RESEARCH SCHEME.

STATISTICAL STUDIES OF THE ANALYTICAL DATA ACCUMULATED IN THE COURSE OF THE BARLEY INVESTIGATIONS.

1.—THE PREDICTION OF EXTRACT.

By L. R. BISHOP, M.A., Ph.D.

PART I.—GENERAL.

It was suggested tentatively in an earlier Report (this *Journ.*, 1928, 101. *Roth. Mem.* Vol. 14) that in samples of any given variety of barley, the amount of nitrogen in the form of each of the separate proteins is regularly related, in the manner described in that communication, to the total nitrogen of the grain. It was further suggested that this regularity is uninfluenced by such conditions as soil, season and manuring. Subsequent studies have confirmed this relationship and made it clear that the amounts of the individual proteins can be calculated, for any given variety, from the total nitrogen content of the grain. In consequence the total nitrogen content is a good criterion of the "quality" of barley, in so far as this is affected by the amounts of each of these proteins, and in elucidating the part played by the nitrogen compounds in barley "quality," renewed confidence may be placed in the total nitrogen content. The present study is one result of the numerous applications of this principle.

It has often been suggested that the amount of nitrogen in barley is inversely related to the amount of starch in the grain or of extract obtainable from the malt, but the assertion has been denied or doubted and at present the relation is generally regarded as not strictly but only approximately true. It has also been asserted, and denied, that the larger the corns (*i.e.*, the smaller the proportion of husk and germ) the greater will be the amount of extract. The very large and valuable body of analytical data accumulated under the Institute of Brewing Research Scheme and published in the Reports on the "Influence of Soil, Season and Manuring on the Quality and Growth of Barley," 1924, *et seq.* has made

possible a re-examination of these questions on a much sounder basis. Modern statistical methods have been employed which give not only the best estimate of the relationships which exist, but also a measure of their accuracy.

The results of this study of the relationship between the combined effects of nitrogen content and thousand corn weight of barley on the one hand, and on the other of the extract obtained from the corresponding malt are sufficiently encouraging to suggest that the estimation of nitrogen content and thousand corn weight should be of definite practical use in the valuation of barley and in the conduct of malting operations. In view of this it has been thought desirable to divide this paper into two distinct parts, to detail in the first some of the practical applications of the results and in the second, to describe the statistical methods by which these results were obtained and substantiated.

* * * *

In 1926 a series of 34 barleys grown from the same pure strain of Plumage-Archer seed was malted in lots of 7 to 25 quarters by Messrs. Gilstrap, Earp & Co., Ltd. The moisture, nitrogen content and thousand corn weight of the original unscreened barleys were determined as were the moisture and extract of the malts obtained from the same barleys after screening. The analytical results were published at the time (this *Journ.*, 1928, 321).

As a result of the statistical examination, described in detail later in this paper, of these analytical results, it was found that the extract of the malt (from screened barley) could be calculated in 68 per cent. of the samples to within 0.7 lb. per quarter from the following formula based on the nitrogen content and thousand corn weight of the

original unscreened barley, the analytical data being calculated on dry matter.

$$E = 110.1 - 11.2 \times N + 0.18 \times G$$

in which E = extract in brewers' pounds per quarter of dry malt.

N = nitrogen percentage on dry barley

G = weight of 1000 dry corns in grams.

This equation, which will be referred to as the "extract equation," was obviously calculated only to apply to the particular series of barleys and malts examined. These were all Plumage-Archer barleys of one strain, but they were grown in several different localities under varying conditions of soil, weather and manuring. The nitrogen percentage of the barleys ranged from 1.35 to 1.65 and the extracts of the malts from 97 to 102 lb. (calculated to dry malt). The malting loss also varied considerably. Thus the barleys represented a varied range with very different market valuations, but all of one variety. The agreement between the calculated results and those actually obtained is shown in the following table. (Table I).

It remained to be decided whether the formula was applicable to other samples of English barley grown in different seasons under varying conditions and malted by different maltsters, since only in these circumstances would it be generally applicable to the purchase of barley and the control of malting operations.

The general applicability of the "extract equation" was tested by using the calculations for all other barleys malted in bulk for the Institute researches. These were not sufficient to yield satisfactory equations themselves, but the barleys were grown in different years and at different places and, in addition, they were malted by different maltsters so that they provide a very good test of the formula. The results are given in Table 2 (p. 423). In this table the extract calculated from the equation is compared with that obtained by analysis and also with the extract of the malt made experimentally by the "stocking" method. The different maltsters are referred to under letters and the barleys under the numbers used in the barley research reports. The only other variety of barley which it was possible to test with the data available was Spratt-Archer. The formula was found applicable

TABLE I.

AGREEMENT BETWEEN EXTRACTS OBTAINED AND
PREDICTED.

1926 Bulk Malts.

Extract, lb. per Quarter on Dry Malt.

Place.	Plot.	Calculated.	Found by analysis	found—calculated.
Dunbar ..	1	100.29	100.2	— 0.1
	2	100.29	99.5	— 0.8
Dunmow ..	3	99.02	99.7	+ 0.7
	4	100.16	100.4	+ 0.2
	5	100.50	100.2	— 0.3
	6	99.45	100.1	+ 0.7
Wellington ..	11	100.32	100.3	0
	12	99.91	99.7	— 0.2
	13	99.91	100.3	+ 0.4
	14	101.54	100.9	— 0.6
Chiselborough ..	16	100.69	100.8	+ 0.1
	18	100.18	100.8	+ 0.6
	20	101.24	101.8	+ 0.6
	15	99.00	98.8	— 0.2
	17	99.67	100.9	+ 1.2
	19	100.29	101.1	+ 0.9
Sprowston ..	25	100.15	99.0	— 1.2
	26	99.76	99.7	— 0.1
	27	98.24	98.2	0
	28	97.89	97.0	— 0.9
Beverley ..	29	99.79	99.5	— 0.3
	30	99.82	99.1	— 0.7
	31	98.41	99.0	+ 0.6
	32	98.44	97.4	— 1.0
Longniddry ..	33	101.25	101.6	+ 0.4
	34	101.83	102.3	+ 0.5
	35	100.12	100.7	+ 0.6
	36	101.52	101.7	+ 0.2
Rothamsted ..	41	100.11	99.2	— 0.9
	42	99.22	98.1	— 1.1
	43	97.37	99.0	+ 1.6
	44	99.39	98.9	— 0.5
	45	99.14	99.1	0
	46	99.30	99.2	— 0.1

to this variety if 0.5 lb. is added to the extract calculated for Plumage-Archer. That is for Spratt-Archer barley:—

$$E = 110.6 - 11.2 \times N + 0.180 \times G.$$

If any factor in the barleys themselves, apart from the nitrogen and the thousand corn weight, influenced the extracts, then it might be expected that "stocking"

TABLE 2.

COMPARISON OF CALCULATED EXTRACT WITH THAT OBTAINED FROM CORRESPONDING "STOCKING" AND BULK MALTS.

Maltsters	Barley	Extract of dry malt, lb. per quarter.			
		Stocking	Bulk	Calculated	Bulk—Calculated.

1928 SPRATT-ARCHER.

A	401 B Longniddry	99.7	98.9	100.4	-1.5
	402 B "	99.8	99.0	99.8	-0.8
	403 B "	99.4	99.0	100.0	-1.0
	404 B "	99.3	99.1	99.6	-0.5
	405 B "	100.2	99.9	100.4	-0.5
	406 B "	101.8	101.3	101.6	-0.3
B	407/10 Wellingore	100.7	100.4	99.0	+1.4
	408/11 "	100.9	101.6	100.7	+0.9
	409/12 "	99.8	101.2	98.9	+2.3
C	425/8 Fitzhead	101.0	100.5	100.5	0
	426/9 "	101.9	100.9	100.3	+0.6
	427/30 "	101.3	100.9	100.1	+0.8

1927 SPRATT-ARCHER.

A	401/4B Longniddry	98.3	98.9	98.7	+0.2
	402/5B "	100.1	100.8	100.8	0
	403/6B "	98.6	100.1	99.9	+0.2
B	414 B Kings Lynn	99.8	101.8	99.1	+2.7
	413 B " "	100.8	101.5	101.0	+0.5
	415 B " "	100.3	101.8	100.0	+1.8
	416 B " "	101.1	101.5	101.1	+0.4
	418 B Sprowston	100.7	102.0	101.0	+1.0
	417 B "	101.8	100.9	101.9	-1.0
C	427 B Fitzhead	100.3	100.8	100.5	+0.3
	425 B "	100.3	100.9	100.8	+0.1
	426 B "	100.3	100.6	100.3	+0.3

1926 SPRATT-ARCHER.

D	7 Cawkwell	96.3	95.9	96.2	-0.3
	8 "	99.1	97.6	98.6	+1.0
	9 "	97.6	96.6	95.8	+0.8
	10 "	98.6	99.0	98.1	+0.9

TABLE 2 (Continued.)

Maltsters	Barley	Stocking	Bulk	Calculated	Bulk—Calculated.
1924 PLUMAGE-ARCHER					
D	Walcott, bulked Wellingore „	97·6 98·9	101·1 101·0	100·0 101·3	+1·1 } -0·3 } +0·4
B	Orwell, bulked Dunmow „	98·6 98·9	101·5 101·3	100·5 100·9	+1·0 } +0·4 } +0·7
1922 PLUMAGE-ARCHER.					
E	Barneyhill, bulked	98·5	99·8	101·6	-1·8
D	(1) Wellingore (2) „ (3) „ (4) „ (5) „	96·2 97·5 97·7 96·9 98·3	96·9 98·7 98·7 97·3 99·0	97·7 97·4 97·7 96·6 98·4	-0·8 } +1·3 } +1·0 } +0·7 } +0·6 } +0·6
	(1) Walcott (2) „ (3) „ (4) „ (5) „	95·3 94·6 94·5 94·5 95·1	98·5 97·7 98·0 98·0 97·9	97·6 95·2 96·2 95·6 97·4	+0·9 } +2·5 } +1·8 } +2·4 } +0·5 } +1·6

malting of the actual samples would give results in closer agreement with bulk malting than the predictions given by the equation. Actually the predictions give results which are very significantly closer to those obtained in the bulk maltings examined, as shown by the statistical test for significance known as the "Z" test. For an explanation of this see—R. A. Fisher, *Statistical Methods for Research Workers*. Section 41, p. 194. Third Edition 1930.

In 1927 the analyses used for the prediction were of the screened samples malted, but in the other years the analyses were of unscreened barley which was screened before malting. The lack of screening effect is explained later (pages 425 and 431).

Variations in soil and season similarly appear to have no marked influence on the accuracy of the results, as the barleys referred to in Table 2 were grown under different conditions from those of the 1926 series on which the equation was based.

The test of the equation provided by these results is very stringent and suffers from

several disadvantages in comparison with its practical application. For instance the Walcott barleys of 1922 were so unsatisfactory that they would never have been malted commercially and consequently the agreements here are bad.

The main source of the differences between prediction and analysis is variation in malting conditions as shown by the results obtained by different maltsters. For each individual firm these differences are fairly constant from year to year. It will be seen for instance that maltster A obtains from 1 to 2 lb. less extract than B. Maltsters C and D obtain results which are close to the predicted but B's are consistently high.

It is thus clear that the equation as it stands will give a relative figure for the extract from barleys malted by any given maltster. Moreover the equation can be adjusted to give figures suited to any given malting conditions. Thus with maltster B's results an average correction of +1·1 lb. can be made. The predictions are then as close as for the other maltsters. See Table 3.

TABLE 3.
PREDICTIONS TO SUIT MALTSTER B.

Year	1928			1927			
Barley	407/10	408/11	409/12	414B	413B	415B	416B
Differences between analysis and calculation ..	+0.3	-0.2	+1.2	+1.6	-0.6	+0.7	-0.7

Year	1927		1924	
Barley	418B	417B	Orwell	Dunmow
Differences. ..	-0.1	+1.0	-0.1	-0.7

The results in Table 2 (p. 424) are not numerous enough for sound conclusions, but they suggest that when the "extract equation" is used for any Plumage-Archer or, with the appropriate alteration, for any Spratt-Archer barley malted by any maltster the standard error of the prediction will be ± 1.1 lb. This implies nothing about the accuracy of the agreement in any given case, but it does imply that 68.5 per cent. of the predictions will be within 1.1 lb. of the results actually obtained, while 95.5 per cent. of the predictions will be within 2.2 lb. of those obtained. Probably, when adjusted for any given maltster, the predictions will have a standard error of about ± 0.8 lb., i.e., 68.5 per cent. of the predictions will be within 0.8 lb. and 95.5 per cent. within 1.6 lb. The definition of the term "standard error" implies that 68.5 per cent. of the results will fall within the figure given, and 95.5 per cent. within twice that figure.

All that is necessary for any maltster to do is to find from a number of tests with either Plumage-Archer or Spratt-Archer barley, the average amount by which his predicted and obtained results differ and adjust the constant of the equation (110.1 or 110.6) by a corresponding amount, e.g., with maltster

B (110.1 + 1.1) the equation becomes for Plumage-Archer barley.

$$E = 111.2 - 11.2 \times N + 0.18 \times G.$$

In the second part of this paper it is shown that the nitrogen factor varies with malting conditions but for ordinary conditions the figure given (11.2) is probably sufficiently accurate.

Effect of Screening.—It will have been noticed that unscreened barley was used in most cases for the prediction of the extract and this has been compared with the results obtained with malt made from the corresponding screened barley. There is a tradition that screening increases the extract obtained. This will be so of course if stones, half corns and weed seeds are removed, and may be true also if smaller grain of a different variety is removed from a mixed sample, but is not true otherwise at least for unmixed English barleys. The reason for this is discussed in the second part of the paper. It will be sufficient here to give a table of all the Institute comparison maltings of screened and unscreened samples, which, indicates that screening *lowers* the extract—see Table 4. This lowering is on the average 0.4 lb. and the value is clearly significant (by a Z test).

TABLE 4.

EFFECT ON EXTRACT OF SCREENING BARLEY.
(Comparison Stocking Maltings).

Barley.	Extract on dry malt lb. per quarter.		Difference= Effect of Screening.
	Unscreened	Screened	
1927			
401/4	98·9	98·3	—0·6
402/5	100·4	100·1	—0·3
403/6	98·6	98·6	0
427	100·8	100·3	—0·5
425	100·7	100·3	—0·4
426	100·6	100·3	—0·3
1928			
140	101·2	99·7	—1·5
402	100·1	99·8	—0·3
403	100·4	99·4	—1·0
404	100·2	99·3	—0·9
405	101·8	100·2	—1·6
406	102·0	101·8	—0·2
407/10	100·2	100·7	+0·5
408/11	101·6	100·9	—0·7
409/12	100·2	99·8	—0·4
425/8	101·1	101·0	—0·1
426/9	101·3	101·9	+0·6
427/30	101·1	101·3	+0·2

Effect of Malting Conditions.—It is possible by varying the malting conditions, for example, by over or under modification to alter the extract obtained from any given barley. In consequence when an equation for average conditions for any one variety has been obtained by a maltster, its use will enable him to detect deviations from his usual procedure which may have occurred. It is therefore suggested on the basis of these results that *this formula will be sufficiently accurate as a control of malting operations and for the prediction of extract for valuation purposes.*

No attempt has been made so far to derive an equation for use with foreign barley, or for any of the varieties grown in this country, other than Plumage-Archer or Spratt-Archer. The method proposed should however be equally applicable to all barleys and the appropriate equations could be calculated when the necessary data are available.

Notes on Use of Equation.

In the application of the method there are several practical points which must be borne in mind.

(1) The most important is that the sampling for analysis should be very carefully done *i.e.* small samples should be taken all over the bulk (even from screened barley or malt) and well mixed to give the sample for analysis. Otherwise sampling errors will cause a great increase in the "standard error" of the results for which the equation will be wrongly blamed.

(2) It is sufficient to analyse the unscreened barley, but laboratory screening of the sample would be preferable and would have the incidental advantage of giving an estimate of the amount of "tailings."

(3) The equation does not apply to samples which do not germinate well.

(4) The equations given should be used only for Plumage-Archer and Spratt-Archer barleys.

(5) It must be remembered that the formula gives the amount of extract on *dry* malt, not on sample. Similarly, the nitrogen percentage and thousand corn weight used in the calculation are those of *dry* barley.

It is suggested that the following laboratory estimations are made. (1) (optional) percentage of tailings; (2) moisture percentage; (3) nitrogen percentage; (4) thousand corn weight.

Attempts are being made in this laboratory to find means of speeding up the required estimations so that it may be possible to complete them within one to two hours.

Application.—An actual case is given as an example of the application of the "Extract equation" to the control of malting operations. The details were kindly supplied by a firm of maltsters and refer to a carefully selected range of Plumage-Archer barleys which were bulked to cover a large contract in which extract was an important factor. A series of steepings from this bulk had consistently given extracts of over 100 lb. on dry malt, when a particular floor fell to 99 lb. Hand examination of the barley failed to detect any reason for the lower extract, but analysis and calculation from the "Extract equation" immediately indicated that no fault was to be found with the malting operations and that the lower extract was all that was to be expected from the barley steeped. The

details are given in Table 5. This particular maltster found it necessary to subtract 1.5 from the result given by the "Extract equation" to meet his conditions and the formula actually used was :

$$E = 108.6 - 11.2 \times N + 0.18 \times G.$$

TABLE 5.
APPLICATION OF "EXTRACT" EQUATION.

Steeping	N. percent. on dry	1000 corn wt. of dry barley	Extract, lb. on dry malt.	Calculated	
				Calculated	Analysis
1	1.304	43.29	42.0	101.6	100.4
2	1.300	42.16	for	101.6	101.6
3	1.247	43.60	calcn	102.2	100.5
4	1.545	43.60		98.9	99.1

PART II.—STATISTICAL EXAMINATION.

PREVIOUS RESEARCHES.

The opinions of previous workers on the relation between nitrogen content and extract are given by H. F. E. Hulton in Section IX. of his Report on Nitrogenous Matter in Brewing (this *Journ.*, 1922, 103-9) and need not be repeated here. Summarising, Hulton states that out of twenty-five authors who have examined the relation between nitrogen content and extract, thirteen believe that there is a definite inverse relation, nine are doubtful, and three deny that any such relation exists.

Fewer studies have been made of the possible effect of thousand corn weight on extract yield and it would appear that opinions are both for and against the existence of such a relation. Since Hulton's Report was written Scharnagel (*Z. ges. Brauw.*, 1927, 50, 185) has claimed that there is no relation between extract and thousand corn weight. These conflicting views are due to the lack of statistical treatment, scantiness of the data examined, to the grouping together of different varieties, and probably to differences in modification of the different malts.

Several other methods of estimation of relative extract yields have been proposed. The one apparently in use in Sweden and Germany is to estimate the starch or extract content of the barley. This is a laborious operation and it is necessary to estimate the nitrogen content as well, owing to the effect of this on malting loss. Hastie (this *Journ.*, 1926, 343) recommends the valuation of barley for distillers' malt by the estimation of

the starch content and germinative capacity. However, he gives no quantitative relation, and as pointed out above it is necessary to estimate also the nitrogen content. The author is in agreement with Hastie when he points out how economically unsound it is to buy barley or malt on its appearance alone without the assistance of an objective measure of value, such as that afforded by some method of extract prediction.

STATISTICAL STUDY OF THE INSTITUTE DATA.

A preliminary empirical study suggested that the relation of nitrogen content and thousand corn weight of barleys to the extracts of the resulting malts was close enough to be of practical value. The data were then examined by appropriate statistical methods, since, when using sufficient suitable data, statistical methods can give, to a question such as the present one, an answer which is independent of personal bias. The method used is given by R. A. Fisher in "*Statistical Methods for Research Workers*," Section 29, p 132 of Third Edition, 1930.

The statistical calculations yield a *regression equation*, that is an equation such as will give the best agreement possible between the observed and calculated results. For instance, in the regression equation already dealt with ($E = 110.1 - 11.2 \times N + 0.18 \times G$) no other set of values will give as close an agreement between the extracts calculated and those actually obtained. This applies, of course, only to the set of figures and variants used in the calculations.

In Table 1 (p. 422) the agreement between the calculated and the observed extract values is shown. The standard error derived from these figures by statistical methods is 0.7 lb. and this implies that 68.5 per cent. of the calculated values will be within ± 0.7 lb. of the observed, and 95.5 per cent. will be within ± 1.4 (*i.e.* 2×0.7) lb. The remaining 4.5 per cent. will be outside this range.

The accuracy of the individual factors in the equation is measured in a similar manner. For instance, in the "extract equation" the standard error of the nitrogen factor is 1.130, *i.e.*, the value lies between 12.5 ($11.2 + 1.3$) and 9.9 ($11.2 - 1.3$) with a probability of 68.5 chances out of 100. That is, the fact that the figure of exactly 11.2 gives the best fit is the result of calcu-

lation from the available data only, and the variation in the agreements is such that the chances are 68·5 out of 100 that the true value lies between 12·5 and 9·9. Since the value of 11·2 is much more than twice its standard error (1·3) it is exceedingly improbable that the relation obtained is due to pure chance. In other words, the figures demonstrate that there is a really significant inverse relation between the nitrogen content of these particular barleys and the extracts of their malts.

Similarly the equation shows a direct relation between the thousand corn weight and the extract. The factor is here $0·18 \pm 0·07$. Since 0·18 is more than twice the standard error it is very unlikely also that this relation is due to chance. When the number of cases studied is less than 50 the probabilities are somewhat smaller than those given.

"STOCKING" RESULTS.

Most of the Institute data available applied only to barleys grown in experiments and malted in "stocking." As the quality of these barleys varied widely from "grinding barley" to high class malting barley, and as they were grown under such varying soil conditions over a number of years and the modification arrived at varied somewhat

from year to year, they appeared to offer the necessary material on which to form an idea of the *maximum* error involved in the prediction of extract from an equation. This analytical data has consequently been examined in the same way as the 1926 set of bulk malted barleys and has been found to supply further confirmation of the value and reliability of the method. This examination has in addition furnished examples which show that it is possible to deduce from the analytical data, conclusions as to the degree of modification during malting.

Regression equations were calculated for each year of the Institute results, and these together with their standard errors are given in Table 6. The data used in calculating these equations are given in the "Reports on the Influence of Soil, Season and Manuring on the Quality and Growth of Barley," H. M. Lancaster and H. Lloyd Hind (this *Journ.* 1924, *et seq.*)

These figures demonstrate that there is in every case a fairly constant and clearly significant inverse relation between the nitrogen content of the barley and the extract of the resulting malt. This, therefore, supplies a definite and final answer so that *it can now be definitely stated that there is an inverse relation between nitrogen content and extract for one variety of barley.*

TABLE 6.

REGRESSION EQUATIONS.

	Year.	Variety.	Method of Malting.	No. of cases.	Equation.	Standard Error.	S.E. of N. Factor.	S.E. of G Factor.
1	1922	Plumage-Archer	Stocking	89	$E = 108·43 - 8·977 \times N + 0·0807 \times G$	1·512	0·998	0·0499
2	1923	Plumage-Archer	Stocking	87	$E = 101·78 - 6·819 \times N + 0·2051 \times G$	1·921	1·082	0·0669
3	1924	Plumage-Archer	Stocking	81	$E = 104·34 - 5·850 \times N + 0·0708 \times G$	0·755	0·750	0·0432
4	1925	Plumage-Archer	Stocking	92	$E = 101·78 - 12·01 \times N + 0·3587 \times G$	2·138	0·836	0·0551
5	1925	Plumage-Archer N.I.A.B.	Stocking	24	$E = 109·13 - 11·45 \times N + 0·143 \times G$	1·50	2·26	0·0931
6	1926	Plumage-Archer	Stocking	91	$E = 104·23 - 8·490 \times N + 0·2133 \times G$	0·662	0·626	0·0263
7	1926	Plumage-Archer N.I.A.B.	Stocking	38	$E = 101·55 - 7·006 \times N + 0·1807 \times G$	0·726	1·089	0·0599
8	1927	Spratt-Archer	Stocking	78	$E = 109·04 - 10·42 \times N + 0·1798 \times G$	0·958	1·098	0·0464
9	1928	Spratt-Archer	Stocking	50	$E = 108·87 - 11·61 \times N + 0·2552 \times G$	0·759	0·469	0·0434
10	1926	Plumage-Archer	Bulk	34	$E = 110·12 - 11·20 \times N + 0·1799 \times G$	0·682	1·30	0·0704

Where E = extract in brewer's pounds per quarter (336 lb.) of dry malt.
 N = nitrogen percentage on dry barley.
 G = weight of 1,000 dry corns in grms.

Furthermore there is in each equation a direct relation between the extract and the thousand corn weight of barley; values ranging from about 0.15 to 0.25, in the units employed, apply in most cases. In three out of the ten equations this factor fails to attain significance. In one of these (No. 5) the failure is probably due to the small number of samples available. In the other two exceptional cases (Nos. 1 & 3) the thousand corn weights differ from those of other years in that a proportion are heavier than 42 grms. A study of the residual differences (i.e., of differences between observed and predicted extracts) suggests that above this figure the increase of extract with size of grain does not continue to be as large, so that in these cases the data could be better fitted by adding a squared term to the equation:

$$E = a - bN + cG - d(G)^2$$

but this added complication will not be further considered in this paper. Allowance can be made for it in the "extract equation" by taking as 42 grms., all thousand corn weights above this value. Taking these various considerations into account it can be said on the basis of these results that it is beyond doubt that the amount of extract available from the malt increases with increase in weight of the original barley grains (at least up to a value of about 42 grms. per thousand corns).

The relation between nitrogen content and extract appears, from a study of residual differences, to be rectilinear. The factor is, however, larger than would be expected if it were due simply to the replacement of starch by protein; this can be shown by converting the equation to give the extract as a percentage on dry malt. This has been done for the nitrogen factor in the following table (Table 7), where the numbers in the top row refer to the equations so numbered in Table 6 (p. 428).

From Haase's well known statement that an increase of one per cent. in the protein content of barley corresponds with a decrease of one per cent. in the extract of the malt it would be expected that the nitrogen factors in this table would be about 5.8, implying that one per cent. of protein (nitrogen \times 5.8) replaces one per cent. of starch. It may be noted here that the customary factor for converting nitrogen into protein, 6.25, is derived from animal proteins and is too large for plant proteins. The factor in these equations is, however, seen to be greater in most cases, than 5.8. The explanation of this lies partly in the effect of the amount of protein on malting loss; for besides replacing an equivalent percentage of starch, larger amounts of protein result in larger malting losses by increasing the amount both of rootlets and of respiration. This is brought to light also in Swedish results where the extract or starch content of barleys is measured. Such a method allows for replacement of starch by protein and for the effect of weight of grain, but it is found that the nitrogen content has to be taken into account as well. (R. Steenhoff. *Sven. Brygg. Foren.* 1927, 171). This is because the higher the nitrogen content of the barley the more potential extract is lost in malting.

The amount of malting loss and hence the nitrogen effect depends on the flooring conditions, i.e., it increases with increasing rootlet growth and respiration. The size of the nitrogen factor is therefore a measure of the degree of "modification" (used here in a wide sense). For instance in 1923 (-5.20) and 1924 (-4.46) it would appear that on the average the barleys on which the equations were based were undermodified, while in 1925 (-9.16) they were overmodified. Independent evidence, to be published later, from the amount of permanently soluble nitrogen supports these conclusions, and with the 1924 barleys the maltster noted that

TABLE 7.

NITROGEN FACTORS FOR EXTRACT AS A PERCENTAGE ON DRY MALT.

(N. Constants of Table 6, Multiplied by 0.763).

Equation No.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
N. Factor ..	-6.85	-5.20	-4.46	-9.16	-8.74	-6.48	-5.35	-7.95	-8.86	-8.55

"Another day's flooring would probably have improved the extracts."

The nitrogen factor in the equations has therefore a definite significance. Its size is the result of the replacement of starch by protein together with a varying addition due to the relation between the amount of malting loss and the amount of nitrogen present; and the magnitude of this addition depends on flooring conditions.

At first sight the equations in Table 6 (p. 428) appear so different that it looks as if the combined effects of season and of changed malting conditions were altering the relations so markedly that the equations would give very different results. This is not really so, for it will be seen from Table 8 that for the average barley the results are consistent though they differ more in the exceptional extreme cases. In this table are given the extracts calculated from the corresponding equations for "high extract," "low extract" and "average" barleys.

the barleys malted for the Barley Research was unsound malting material and in all these years the standard error is less than 1.0. It is lowest in the "vintage year" 1926.

The exceptional barleys in the bad years are those in which the observed extracts fall well below the calculated, and with these a low diastatic power coincides with a high sinker test, which indicates that many grains had not germinated. This surmise was confirmed by examining the stored samples in a diaphanoscope. Large numbers of unmodified grains were seen in the exceptional samples. An empirical rule was noted here. The 1922 malts (where sinker test results are given) showed several exceptionally low results and in these the number of sinkers was greater than the diastatic power in Lintner degrees ($D-S < 0$). When the diastase *minus* sinkers was between 0 and 20 the results tended to be about 0.7 lb. below average. When $D-S > 20$ then the extracts

TABLE 8.

EXTRACTS CALCULATED FROM THE EQUATIONS IN TABLE 6.

Variety.	Plumage-Archer							Spratt-Archer		Plumage-Archer.
Equation No. ..	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
"High Extract" Barley, N = 1.2% G = 42.0	101.0	102.2	100.3	102.4	101.4	103.0	101.0	104.1	105.5	104.3
"Average" Barley N = 1.5% G = 38.0 ..	98.0	99.4	98.3	97.4	97.4	99.6	98.1	100.2	101.2	100.2
"Low Extract" Barley, N = 1.7 G = 32.0 ..	95.7	96.8	97.7	92.8	94.2	96.6	95.6	97.1	97.3	96.8

The variations seen in this table in the results calculated from equations based on stocking maltings are due in part to variations in the conditions of experimental malting which, as explained above, alter the size of the nitrogen factor, *e.g.*, the 1924 barleys were undermalted (on the average) as shown by the small nitrogen factor (see Table 7, p. 429) and supported by independent evidence. The other source of the larger discrepancies is individual barleys which have been experimentally malted, but would never have been malted in practice. In the years 1924, 1926, 1927, and 1928, only a small proportion of

tended to be 0.7 above average. The rationale of this rule would appear to be that the combined effects of lack of diastase and bad modification in many corns markedly reduce the extract. In the most striking case, barley No. 71, 1925, the diastatic power was 14 and there were 46 sinkers out of 100 corns ($D-S = -32$). This malt gave an extract 9.7 lb. below the calculated. Such barleys would never have been malted in practice and it is obvious that if they were omitted, the equations for 1922, 1923 and 1925 would have smaller standard errors.

The stocking equations are calculated for

the Institute's experimental barleys (a very varied assortment) where the malting conditions are fixed for all barleys, malted at one time, whereas different barleys require different conditions for similar modification. Under these circumstances the stocking equations are of use only in establishing the validity of such predictions, and it must be emphasised that they are not regarded here as of practical value. In fact, in the "bad" years when many of the barleys were only of grinding quality and the fixed conditions clearly unsuited to all samples, the standard errors may be taken as a measure of the maximum possible error of the method.

THE "EXTRACT EQUATION."

It is only in 1926 that there are sufficient results of bulk maltings to yield a satisfactory equation. This equation (10), Table 6, (p. 428), does, however, appear to be reliable for Plumage-Archer barley of fair average malting quality malted under normal flooring and kilning conditions. The practical application of this equation has already been dealt with in Part I.

The standard error (0.68) is as low as in the best of the stocking equations.

SCREENING.

It is noteworthy that the nitrogen contents and thousand corn weights used are those of the barley "as received" while the bulk malting was done on screened samples. Apart from the removal of foreign matter this introduces no large errors into the predictions. The reason for this is, that the small grain removed from an unmixed sample (i.e., barley of one variety and from one source) gives about the same extract as the corresponding bulk. Although the size of the smaller grain tends to reduce the extract yield, yet this is approximately counter-balanced by the fact that, in an unmixed sample, the smaller grain has a lower nitrogen percentage. Table 9 below gives some results which show this. Here results are given for samples of grain from various places which

were separated by sieving into grain of different sizes and the nitrogen contents of the large and small grain were determined. Similar results are given for Hanna barley by Jalowetz (*Woch.-Brau.* 1917, 24, 286).

A practical proof of this lack of screening effect on extract yield is given in Table 4 (p. 426) where the extracts of comparison maltings of screened and unscreened barleys are given. These even show a slight but clearly significant *reduction* of extract as a result of screening out small grain.

EFFECT OF MALTING CONDITIONS.

It was indicated in Part I. that in the practical use of the "extract equation" it is sufficient to adjust the constant for different malting firms (see p. 425). It might be expected that varying malting conditions between individual floors or the effects of soil and season on extract would be large enough to make the equation valueless. Both of these possible sources of variation are affecting the accuracy of the results in Table 2 (p. 423). But, since in this table the differences between obtained and predicted extracts are fairly constant for one maltster, even from year to year, it is concluded that within one season the piece to piece variations should be small enough to be negligible in practice. It is hoped that further evidence on this point will be available in the near future.

The "extract" equation will in any case give a relative estimate of the extract-yielding power of barleys and it can be converted to give absolute values for any maltster. As indicated in Part I. adjustment of the constant appears sufficient in most cases. When conditions are markedly different from those in the bulk maltings studied, then adjustment of the nitrogen factor also becomes necessary. For, as demonstrated earlier (p. 429) the size of this varies with the degree of modification.

In Table 2 (p. 423) it is also shown that one maltster may obtain extracts which are on an

TABLE 9.
RELATION BETWEEN WEIGHT OF GRAIN AND NITROGEN CONTENT.

	Standwell Cannington 1928		Standwell Leegomery 1925		Standwell Leegomery 1927		Standwell Rothamsted 1928		F.122 Long Sutton 1926	
1,000 corn weight dry	50.28	39.44	49.91	39.52	48.51	37.52	50.23	40.55	35.31	20.80
Nitrogen percentage	1.917	1.625	1.517	1.337	1.880	1.654	2.235	1.972	1.396	1.384

average 1.0 lb. more than the predicted. Another may obtain 0.5 lb. less than the predicted. Such a comparison of obtained and predicted results affords a method of comparing the results of different malting methods even with different barleys. This comparison of extract yield is obviously not everything in comparing malting values.

In the experimental stocking maltings it appears that the conditions varied more from year to year than in the bulk maltings. The changes can best be followed by comparing among themselves the calculated results in Table 8 (p. 430). It must be remembered that part of the variation here is due to the badly germinating samples malted. These have lowered distinctly the values for the "low extract" barleys in 1922 and 1925 (Equations Nos. 1, 4 and 5).

EFFECT OF SOIL AND SEASON.

Soil and season have marked effects on extract yield through their effects on nitrogen content and thousand corn weight. These are allowed for in the equation and, apart from these, soil and season have no important effects on extract. Conditions of harvest weather and subsequent storage which lead to bad germination form the one exception to this dictum. The evidence for the lack of soil and seasonal interference with the prediction may be indicated as follows:—

(a) *From the bulk results.*

The major part of the variations in Table 2 (p. 423) may be accounted for by the variation between different malting firms and the sampling and analytical errors. Differing soils and seasons cannot therefore be causing any very marked effects on the differences between observed and predicted extracts, although any such effects cannot be clearly separated here.

(b) *From the experimental stocking malts.*

A study of the differences between observed and predicted extracts for successive years shows no indication of a regular relation with the nature of the soil or the rainfall. In one case, the Plumage-Archer controls to the variety plots (N.I.A.B.), it is possible to test the significance of the place variance compared with the total variance. The result (of a Z test) shows that there is no significant difference between places. That is, the variations come from the individual samples and all the samples from one place are not influenced in one direction by the

nature of the soil or the weather. Similarly the experimental malting results from year to year show no marked effects of season. This is indicated by the similarity of the results in Table 8 (p. 430). Differences shown here from year to year may be accounted for by differences in malting conditions (from external evidence and from the nitrogen factor) and by varietal differences. The general values in Table 8 are lowered in some cases by the strikingly exceptional barleys, occurring chiefly in the bad seasons, whose extracts fall well below the predicted results. As mentioned above these variations can be accounted for by bad germination, resulting in bad modification and lowered diastatic power.

Such bad germination is the result of harvest weather and subsequent storage conditions and this is the only soil or seasonal effect which could be traced. In the good years, when all the barleys germinated well, the standard errors (0.65-0.95) may be low enough to be due only to errors caused by sampling and analysis; but though there may be another cause of variation which is not yet traced, it cannot be very important. Immature barleys might, as a result of the poor germination, give extracts below those predicted.

EFFECT OF VARIETY.

The Institute of Brewing analyses of the barley varieties grown by the National Institute of Agricultural Botany would afford very good material for variety equations if there were more analyses of each variety. The few available direct comparisons of varietal effect show that the increases for Spratt-Archer over Plumage-Archer range from 0 to +1.0 lb. Probably +0.5 lb. represents the varietal difference accurately enough at all nitrogen contents and thousand corn weights.

The yield of extract per acre is probably about the same for the two varieties since they both give about the same yield of grain and nitrogen content on the same soil, but Plumage-Archer has significantly larger grain. This would approximately compensate for the fact that Plumage-Archer grain gives slightly lower extract than Spratt-Archer grain of corresponding thousand corn weight and nitrogen content.

It has only been possible to test the equation for these two varieties but it appears probable that the equation given

may be found to apply to other two-rowed varieties with similar small modifications.

BEARING OF THE RESULTS ON "QUALITY" IN BARLEY.

The amount of extract yielded as malt is a factor which affects the value of barley, but simple arithmetic will demonstrate that with the higher valued barleys by far the greater part of the greatly increased price is not paid for the increased extract. It now appears possible for a valuer to calculate the amount of extract. Therefore this factor in value can be measured leaving the less tangible factors in quality and value to be elucidated separately.

Another factor in "quality" is the amount and nature of the nitrogen compounds in wort. A determination of the nitrogen content of the barley is needed for the extract prediction and a later communication will show how this figure may be simultaneously of value in indicating the nitrogenous composition of the resulting wort.

SUMMARY.

As the result of a statistical study it is established beyond doubt that there is an inverse relation between the nitrogen contents of barley of one variety and the extract yield of the resulting malt. An increase of extract with increase of grain size is demonstrated almost as conclusively. Soil and seasonal conditions appear to affect the extract only through their effects on nitrogen content and thousand corn weight. The one exception to this is due to conditions which give badly germinating samples. These give low extracts.

It is suggested that, for the purpose of valuation and malting control, the extract a barley should yield as malt can be predicted accurately enough from an equation allowing for the effects of the amount of proteins and for the grain size. Such an equation can be constructed for each separate variety wherever the necessary data are available for a set of malts of similar modification. A series of maltings of a pure line of *Plumage-Archer* barley gave the following "extract equation" which probably gives results for average modification :—

$$E = 110.1 - 11.2 \times N + 0.18 \times G.$$

Where E = the extract of the dry malt in lb. per quarter.

N = the nitrogen content on dry barley, and

G = the weight of a thousand dry corns in grms.

This equation predicts the extracts of the malts examined within 0.7 lb. in 68 per cent. of the cases. It was applied to other bulk maltings made in different years by different maltsters and predicted within 1.1 lb. the extracts obtained in 68 per cent. of the cases. It can be adjusted to meet the requirements of most maltsters simply by adjustment of the constant (110.1), when the error will probably not be more than about 0.8 lb. in 68 per cent. of the cases. 95 per cent. of the extracts are predicted with an error less than twice the values given.

The equation was found to apply to *Spratt-Archer* barley if a constant of 110.6 is substituted. Other varieties can probably be dealt with by equations of the same type.

The "extract equation" is given as a type of the formula necessary and not as a rigid equation applicable to all conditions. However, the available tests with very diverse conditions suggest, that in most cases it will be sufficient for practical purposes to add to, or subtract from the constant (110.1), the average difference between a number of predicted and observed results. The size of the nitrogen factor varies with, and is a measure of, the degree of modification during malting. So that an equation of closer approximation can be obtained by the statistical examination of the results of any given maltings.

A simple slide rule can be constructed to give the results or reference may be made to the table given as an Appendix (Table 10 p.434). The required estimations of nitrogen content, thousand corn weight and moisture content can be carried out fairly rapidly and especially rapid methods for each estimation are being studied. If these are satisfactory it should be possible to complete the estimations within one to two hours.

It must be strongly emphasised that if such a scheme is adopted the sampling must be most carefully done. Small samples should be taken, even from the screened barley or the finished malt, from all over the bulk and should be well mixed to give the final sample for analysis. An error of 0.1 per cent. of nitrogen on dry matter, or, of 5 grms.

in the thousand corn weight results in an error of 1 lb. in the prediction.

Equations of the type given appear to have a wide range of applicability and it would indeed appear that if the sampling and analyses have been correctly carried out, the equation can be regarded, not as a rough approximation, but rather as a standard of reference with which the results obtained may be compared. That is, a comparison of

the predicted results with those obtained will measure the success of the conditions in producing extract and their suitability for given barleys.

The writer wishes to acknowledge his indebtedness to Dr. R. A. Fisher, F.R.S., and to Dr. A. R. Clapham, M.A., for help in the statistical treatment.

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APPENDIX.

FOR PRACTICAL USE.

TABLE 10.

TABULATED VALUES OF EXTRACT ON DRY MALT
FROM EQUATION $E=110.1-11.2 \times N+0.180 \times G$.

1,000 corn weight	Nitrogen Percentage (on dry barley).														
	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75	1.80
42.0	105.3	104.8	104.3	103.7	103.1	102.6	102.0	101.5	100.9	100.3	99.8	99.2	98.6	98.1	97.5
& over															
40.0	105.0	104.4	103.9	103.3	102.8	102.2	101.6	101.1	100.5	100.0	99.4	98.8	98.3	97.7	97.2
38.0	104.6	104.1	103.5	103.0	102.4	101.8	101.3	100.7	100.2	99.6	99.1	98.5	97.9	97.4	96.8
36.0	104.3	103.7	103.2	102.6	102.0	101.5	100.9	100.4	99.8	99.2	98.7	98.1	97.6	97.0	96.4
34.0	103.9	103.3	102.8	102.3	101.7	101.2	100.6	100.0	99.5	98.9	98.3	97.8	97.2	96.7	96.1
32.0	103.5	103.0	102.5	101.9	101.3	100.7	100.2	99.6	99.1	98.5	97.9	97.4	96.8	96.3	95.7
30.0	103.2	102.6	102.1	101.5	101.0	100.4	99.8	99.3	98.7	98.1	97.6	97.0	96.5	95.9	95.3
28.0	102.8	102.3	101.8	101.2	100.6	100.0	99.5	98.9	98.4	97.8	97.2	96.7	96.1	95.6	95.0
grms.															

This is for Plumage-Archer barley. For Spratt-Archer add 0.5 lb.

THE INSTITUTE OF BREWING RESEARCH SCHEME.

BARLEY PROTEIN RESEARCHES.

PREDICTION OF EXTRACT II.

THE EFFECT OF VARIETY ON THE RELATION BETWEEN NITROGEN CONTENT AND EXTRACT.

L. R. BISHOP, M.A., Ph.D., and F. E. DAY, B.Sc., F.I.C.

It has been shown in earlier papers that the quantities of the individual proteins of barley are regularly related to the total protein content of the grain in any one variety, but there are quantitative differences between varieties.¹ Consequently there is no direct means of elucidating the effect of differing quantities of the individual proteins except by comparing barleys of different variety or of different total protein content. Before any effects on brewing value could be separately attributed to these individual proteins it was therefore necessary to determine in what way differences in total nitrogen content or in variety affected the properties of malts.

The present study does this for extract, one of the factors in the brewing value of malt which can be measured quantitatively. One result of this study is that large numbers of varietal analyses are put in a form available for use in practice. The effect of total protein (or total nitrogen content) on extract was first studied chiefly in one variety.² There it was shown that both nitrogen content and grain weight affect the extract of malts, made from Plumage-Archer barley, in the manner indicated by the equation:—

$$(1) E = 110.1 - 11.2 N + 0.18 G.$$

This equation was derived from analysis of a limited number of samples (34) and a limited range of nitrogen content (1.3 — 1.7). In the present study the number and nitrogen range have been extended, giving in consequence more accurate results.

It was shown in the previous paper² that different varieties require some change in the equation and the question arose as to whether it was necessary to change only the constant of the equation (110.1 in the original) or whether the nitrogen in different

varieties behaves differently. This consequence would follow if the individual proteins had specific effects on extract; but none were found in the samples here studied. The importance of the degree of modification of the malt is also shown.

I.—CONSTANCY OF NITROGEN AND THOUSAND CORN WEIGHT EFFECTS ON EXTRACT.

(a) Examination of Six Representative Varieties.

Six varieties were chosen to cover as wide an extract range as possible and six samples of each variety were studied. The extracts of the malts from these samples have been plotted against the nitrogen content of the barleys in Diagram 1. The proof that the effect of thousand corn weight is the same in all varieties has been anticipated—it is known that this effect is in any case small—and the extracts plotted are those calculated for a constant 38 grms. thousand corn weight. That is, 0.2 lb. has been added for every gram that the actual thousand corn weight was below 38 grams and 0.2 lb. subtracted for every gram that the thousand corn weight was above 38 grams.

It is clear from the diagram that in each variety, extract falls off as the nitrogen increases and, since the lines for the different varieties are approximately parallel, the effect of nitrogen content on extract is substantially the same in all the varieties. This implies, for example, that whether compared at 1.0 per cent. of nitrogen, at 2.0 per cent. or at intermediate values Plumage-Archer malts will yield an extract which exceeds by a constant quantity that given by Atlas malts of the corresponding barley nitrogen content.

This leads to the suggestion that a single nitrogen factor can be used for all these varieties and, if the same can be shown for the thousand corn weight effect, then one equation can be used for all varieties except that the constant (A) must be changed for

¹ L. R. Bishop, this *Journ.* 1928, 101; 1930, 336.

² L. R. Bishop. *ibid.* 1930, 421.

RELATION BETWEEN NITROGEN CONTENT AND EXTRACT FOR DIFFERENT VARIETIES.

ALL EXTRACTS CORRECTED TO THAT FOR 38 GMS. 1,000 CORN WEIGHT.

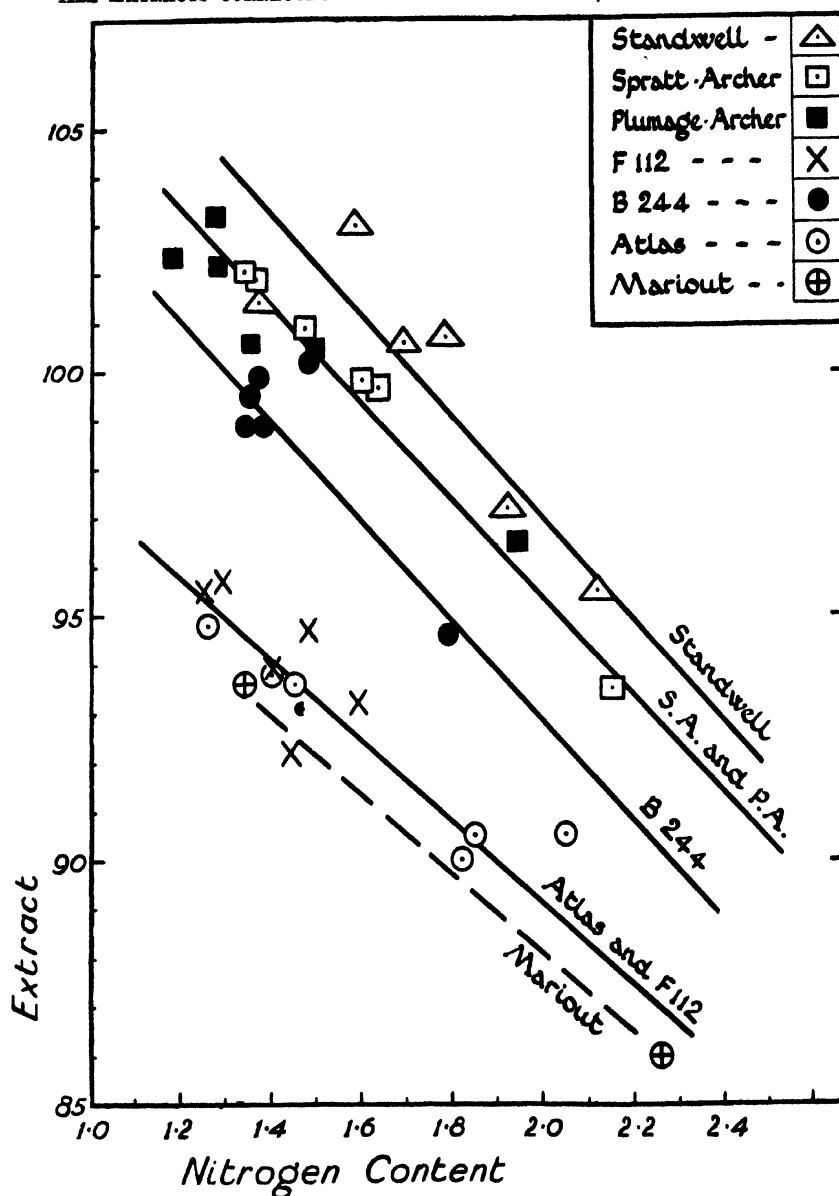


Diagram 1. The quantities of extract yielded by barleys of different varieties are seen to decrease regularly as the nitrogen content of the grain increases. The points fall very close to straight lines which are almost parallel. The results show that the difference between any two varieties in extract is the same whatever the nitrogen content of the grain. For extract calculation it is therefore necessary to know the variety and its extract constant. The diagram illustrates very clearly the individuality and regularity in the behaviour of varieties.

each variety. This "within varieties" equation was calculated statistically from the analytical results and so were the individual equations for each of the six varieties. It was then shown that the nitrogen factors of the individual equations did not differ from one another more than would be expected on the theory of errors. The same was shown for the individual thousand corn weight factors. (This proof is elaborate and is not given here. Details can be supplied if requested). The results imply that one nitrogen factor and one thousand corn weight factor can be used for the varieties tested. In other words nitrogen appears to have the same effect on extract in all these varieties and so does thousand corn weight.

(b) *Examination of 851 Samples.*

An alternative method of proving the same point was afforded by examination of all the sets of data available and calculation of the "within varieties" equation. Equation (2) was thus obtained. In it allowance is made for constant differences in extract between varieties compared at equal nitrogen percentages. If nitrogen had different effects in different varieties then the nitrogen factor in the equation would be vague and uncertain, that is, subject to large errors. If, on the other hand, nitrogen had the same effect in all varieties then the factor would be accurate, that is it would have a small standard error. This was actually found to be the case and varieties with abnormal

nitrogen extract relationships must have been absent or represented only by small numbers. Similar remarks apply to the thousand corn weight.

The equation obtained was:—

$$(2) E = A - 10.42 (\pm 0.28) N + 0.217 (\pm 0.016) G. \pm 1.37$$

Where E = Extract in brewers' lb. per 336 lb. of dry malt, determined by the Institute of Brewing Standard Method.

A = A constant depending on the variety (see below).

N = Nitrogen per cent. on dry barley.

G = Thousand corn weight of dry barley in grams.

The standard errors of the factors are given in brackets.

This equation was derived from analyses of 851 barleys and their malts. They came from a very wide range of soil and seasonal conditions which are too numerous to specify here individually.

The table below shows the sets used:—

The small standard error of the nitrogen factor shows further that experimental stocking and commercial bulk maltings produce very closely similar nitrogen-extract relationships. When the first paper was written the validity of this was questionable, but subsequent results have removed this doubt (see ³ and above).

³ H. M. Lancaster and H. Lloyd Hind, this *Journ.* 1932, 290.

TABLE I.

SETS OF DATA USED IN CALCULATING EQUATION (2).

Year.	Number of Samples.	Variety.	Malting Methods.
1922	89	Plumage-Archer	Stocking.
1923	87	" "	"
1924	81	" "	"
1925	116	" "	"
1926	129	" "	"
1926	34	"	Experimental Bulk.
1927	78	Spratt-Archer	Stocking.
1928	50	"	"
1931	104	Commercial English 2-row	Commercial Bulk.
1931	47	Californian 6-row	" "
Var.	6	Standwell	Stocking.
"	6	Plumage-Archer	"
"	6	Spratt-Archer	"
"	6	Indian	"
"	6	F.112	"
"	6	Atlas	"

TABLE 2.
VARIETAL EXTRACT CONSTANTS
for substitution for A in equation.
 $E = A - 10.5 N + 0.20 G.$

Variety.	Malting Method.	Number of samples.	A.	Standard error of A.	B. Average Extract Yield.
Naked Barley.					
Indian naked	S	3	116.8 -	—	104.0
Two-row Barleys.					
Golden Pheasant	S	10	110.5 c	0.4	98.0
Cambridge 59/120	S	7	110.1 c	0.4	98.0
Standwell	S	10	110.0 c	0.3	100.4
825	S	23	110.0 c	0.1	101.0
824	S	23	109.4 c	0.2	101.0
Beaven's Archer	S	11	109.2 c	0.3	98.0
Webb's Sunrise	S	21	109.2 c	0.2	98.0
Chevallier	S	4	108.9 c	0.2	100.8
35/51	S	12	108.7 c	0.2	101.0
Spratt-Archer	S	39	108.6 c	0.1	101.0
Plumage-Archer	B	34	108.3 -	—	100.0
Plumage	S	4	108.3 c	0.3	101.7
Archer-Goldthorpe	S	10	108.3	0.4	99.0
Archer	S	8	108.2 c	0.6	96.0
Goldthorpe	S	4	107.8 c	0.3	101.1
Gartons 1917	S	6	107.7 c	0.7	95.0
Six-row Barleys.					
B.244	S	7	106.0 c	0.4	97.0
Garton's Square-head	S	7	105.2 c	0.3	95.0
Indian Six-row	S	38	104.8 -	0.2	97.0
Carter's Six-row	S	2	104.6 c	—	99.0
F.112	Sand B	14	103.0 c	0.3	94.0
Tennessee Winter	S	5	102.9 -	0.6	94.0
Atlas	S	12	101.5 -	0.3	93.0

S=Malted in stocking.
B=malted in bulk.
c=corrected for soil and seasonal errors through a control.

TABLE 3.
APPROXIMATE VARIETAL EXTRACT CONSTANTS.
Where only a few samples were available.
Six-row barleys.

Variety.	Malting Method.	Number of samples.	A. Extract Constant	B. Average Extract Yield.
July	B	1	108.5	101.0
O.A.C. 21	Sand B	2	107.3	94.0
Coast	S	2	101.9	90.0
Trebi	Sand B	3	101.3	92.0
Mariout	S	3	101.0	91.0
Smooth Awn	S	1	99.8	89.0
Hero	S	1	99.4	86.0
Vaughan	S	2	98.3	85.0

This general equation may be stated in rounded numbers as:—

$$(3) \dots E = A - 10.5N + 0.20G$$

This equation applies to all the varieties tested, and being based on a much larger number of samples is therefore substituted for the Plumage-Archer equation originally given (1 *loc. cit.*), as it is more accurate and more convenient for general use.

Another result of this more extensive examination was to show that undermodification was probably responsible for the relatively low extracts of malts from barleys with very high thousand corn weight. The limitation put forward in the earlier paper is therefore withdrawn and thousand corn weights above 42 grams should be treated just as those below that figure.

II.—EXTRACT CONSTANTS FOR DIFFERENT VARIETIES.

Having shown that the factors for both nitrogen content and thousand corn weight are similar for all varieties, there remains the constant in the prediction equation and this has been shown to differ considerably in different varieties. In Tables 2 and 3 is given a list of constants calculated for such varieties as it has been possible to test and with the number of samples decided by opportunity.

The constants are for substitution in the general "within varieties" equation (3) given, *i.e.*, in the equation.

$$E = A - 10.5N + 0.20G$$

Where *A* = *The appropriate varietal constant.*

In a large number of cases, varieties have been grown by the National Institute of Agricultural Botany alongside a control [Plumage-Archer (1924) or Spratt-Archer (37/6)]. In these cases it has been possible to eliminate the soil and seasonal effects and obtain what is probably an accurate varietal figure from relatively few samples. These cases are marked by *c* in Table II. They have been adjusted by correcting the extract of the variety by the same amount as the control differs from its own predicted value. The calculation method used has been to predict the extract of both variety and control from the Plumage-Archer equation and subtract the predicted values from the corresponding extracts obtained by analysis. If the differences are represented by $V-v = D$ and $C-c = d$, the correction to be added to

the Plumage-Archer constant is given by $D-d$.

Where the control was not Plumage-Archer itself, Spratt-Archer was used and its constant (108.6) substituted for 108.3. With some varieties no control variety for eliminating interfering factors was available and the results are less exact.

It must be emphasized that these varietal constants are those obtained under approximately normal malting conditions for "pale ale" malts. Wide deviations from these conditions will give other constants, particularly with certain varieties. See Section III.

The standard error of *A* given in Table 2 is the standard error of the mean, *i.e.*, the amount by which the figure given is likely to differ from the true figure. It will be appreciated that where only a few samples are available the figure given is very likely to be inexact. This applies particularly to Table 3.

It will be seen from Tables 2 and 3 that there is an almost continuous series of constants ranging from 110 to 98. This means that varietal effects on extract apart from nitrogen and thousand corn weight may give differences up to 12 brewers' pounds of extract, or as much as 19 lb. when naked barleys are taken into consideration. It is therefore very necessary to know both the variety and its constant when calculating extract from nitrogen and thousand corn weight. Average figures can be given for English and Californian varieties but, since different varieties occur, these are necessarily inexact. (Table 4.)

TABLE 4.

Average value for constant A for commercial samples.

	A.	Range.
English ..	108	107-110
Californian ..	101.5	98-103

The constants *A* are arranged from the point of view of the chemist who wishes to predict the extract. He requires to know the variety, its prediction constant and the nitrogen content and thousand corn weight.

One of the requirements of the buyer is met by the column *B* in Tables 2 and 3, which gives an approximate estimate of the extract yield of the variety under average soil and

seasonal conditions, malted to the degree of modification usual in the samples examined. It will be seen that some of the two-row varieties with high constants do not give the highest extracts, as these varieties tend to be high in the nitrogen content.

III. ACCURACY OF EXTRACT PREDICTION.

Subsequent work has demonstrated the effect on extract of the degree of modification of the barley during malting. This degree of modification is the resultant in the main of two sets of factors, one is the vitality and physical state of the barley at malting (the "missing factor"), the other is the malting conditions employed (times, temperatures, etc.). Studies have shown that, with the normal range of malting conditions and most barleys, the barley factor is as important as malting conditions; each, from a provisional estimate appears responsible for some 5 per cent. of the variation in extract. The ideal aimed at would be to measure the "missing factor" in the barley itself when the extract for given malting conditions could be predicted. In this paper the resultant effect of the two sets of factors has been measured in the malt by the degree of modification. This has been measured, as previously proposed, by the percentage of the total barley nitrogen becoming permanently soluble in the wort.⁴

The importance of the barley factor only becomes prominent with poorer barleys. With "pale ale" grade barleys it is usually not important, and it is estimated that predictions from nitrogen content, thousand corn weight and the appropriate varietal factor (Table 2) should give a standard error of about ± 0.8 lb., as previously suggested (²).

It is among the mild ale grade barleys that the barley factor assumes more importance. These are graded lower than pale ale barleys on external appearance, which is not a reliable guide to the physical state and vitality of the barley (see ⁵); nevertheless, it is chiefly here that the unsound barleys occur and predictions from nitrogen and thousand corn weight show larger errors than ± 0.8 lb.

An equation taking into account the degree of modification eliminates these errors and is useful in checking the determination of

extract on malts. It has, therefore, been calculated for as many varieties as possible. The equation obtained from the analyses of 150 barleys and their malts was:—

$$(4) \dots E = a + 0.12G + 0.11P - 7.5N \dots \pm 0.8 \text{ lb.}$$

where P = percentage of permanently soluble nitrogen on barley total nitrogen. The varieties used and their appropriate constants are given in Table 5.

TABLE 5.
Varietal Constants in Equation (4).

Variety	a	Variety	a
Standwell ..	103.8	Plumage ..	102.6
Chevallier ..	103.2	Goldthorpe ..	102.2
825 ..	102.9	Spratt-Archer ..	102.0
824 ..	102.8	B.244 ..	100.1
35/51 ..	102.6	Californian Bay	
		Brewing* ..	96.3
Plumage-Archer ..	102.6	F.112 ..	95.9

* Atlas, Coast and Tennessee Winter.

The remaining errors come chiefly from errors in sampling and analysis and for closer estimates current practice here needs improvement.

(c) *Analytical and Sampling Errors.*

The importance of avoiding these sources of error is clear. The analysis sample should be made from a mixture of sub-samples taken all over the bulk. Systematic errors in either nitrogen or extract determination do not reveal themselves until the prediction method is used, but here they lead to a large proportion of bad agreements between extract and prediction. It is the extract determination which is liable to the greatest random errors, and occasional determinations may be 1 lb. or more in error if only single determinations are made. Comparison of the results with the prediction will in these cases reveal a discrepancy and repetition of the extract determination will show if this is the source of error. This method of checking has been found useful in several laboratories.

IV. PHYSIOLOGICAL CHARACTERIZATION OF VARIETIES.

The barley grain of all varieties is influenced in composition chiefly by soil and season, and the influence of these is similar in all varieties. The characteristics of varieties show themselves as regular small differences in

⁴ L. R. Bishop, *this Journ.*, 1931, 345.

⁵ E. J. Russell and L. R. Bishop, *ibid* 1933, 287.

composition superimposed on the soil and seasonal effects, *e.g.*, in the samples examined in the Institute series, Golden Pheasant grown beside Plumage-Archer has been regularly 0.16 per cent. higher in nitrogen content⁶, and while Plumage-Archer and Spratt-Archer have given closely corresponding nitrogen contents under all conditions, Spratt-Archer has been regularly about 3 grams lower in thousand corn weight.

The extract constants given in Table 2 are another example of constant varietal difference in composition in spite of the large variations produced by soil and season. Varietal characteristics in composition may therefore be given quantitative expression as *plus* or *minus* so much, when compared with a standard variety—say, Plumage-Archer.

It may, therefore, be suggested that the extract prediction constants (A, Table 2) are useful indices in barley breeding, summarising as they do the characteristics of any variety in a single figure; and the suggestion is made that the mode of inheritance of this figure should be worked out with the object of breeding improved varieties.

Acknowledgements.

The greater proportion of the barleys on which these results are based were grown by the National Institute of Agricultural Botany, in some cases especially for this investigation.

We are very much indebted to this Institute.

The analyses of those grown in the years 1922-26 were made by Mr. Lloyd Hind. For samples and analyses of bulk malts we are indebted to Hugh Baird & Sons, Ltd., and Edward Sutcliffe, Ltd., and to Messrs. G. D. Clarkson, and S. F. Weeden. Altogether the results of analyses of some 1,500 barleys and their malts have been utilised.

SUMMARY.

Nitrogen and thousand corn weight have been shown to have similar, if not the same, effects on the yield of extract in all the varieties studied. There are, therefore, constant differences between varieties in their extract yields at corresponding nitrogen contents and thousand corn weights. Consequently the extract of barleys of any variety can be predicted if the analysis and the appropriate constant are known. A list of a number of these constants is given.

The remaining sources of error are—another factor in the barley, malting conditions and analytical and sampling errors.

The constancy of the extract prediction “constant” for each variety throws light on the physiology of the barley grain and on possibilities in breeding new varieties.

*Rothamsted Experimental Station,
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Herts.*

THE INSTITUTE OF BREWING RESEARCH SCHEME.

REGULARITIES IN THE CARBOHYDRATE COMPOSITION OF BARLEY GRAIN.

By L. R. BISHOP, M.A., Ph.D. and D. MARX, M.Sc.

In the course of investigations on the proteins indications were obtained that there exist in the carbohydrate composition of barley grain regularities which are similar to those demonstrated among the proteins. (L. R. Bishop, this *Journ.*, 1930, 336.) It therefore became desirable to ascertain whether the indications were correct; for, if these regularities could be established in carbohydrate composition, the results would be of considerable importance both in their practical application and in the study of barley metabolism.

The obvious method of attack on this problem was to estimate the quantities of the individual carbohydrates in a number of samples of barley, and in part this has been done. However, this would give results of biochemical interest only, but this work sought to obtain at the same time results of direct practical application by considering, in addition, empirical divisions of the carbohydrates of barley. The empirical estimations included are those for "brewers' extract," crude fibre and a new estimation designated the "insoluble carbohydrate" which aims, as far as possible in a single rapid estimation, to measure the carbohydrate fraction complementary to extract—that of "spent grains." Objections may be raised to the use of such empirical estimations, but experience suggests that, under their appropriate standardised conditions, they give definite, reproducible fractions of the carbohydrates present. While it may be pointed out that the "scientific estimations" of starch, cellulose, lignin and hemicelluloses* are open to similar objections; for a consideration of these estimations shows that in every case they, too, depend on the use of standardised conditions and an empirical factor. In

addition the "scientific" estimations are slow and the entities they claim to estimate are by no means well defined. From the results it will be seen that both types of estimation—the "scientific" and the "empirical"—support the existence of carbohydrate regularity.

This word regularity will be used throughout and it may be pointed out here that it is not confined to that special case of a regular relation—proportionality.

SECTION 1.

METHODS AND RESULTS.

The "insoluble carbohydrate" method was worked out as a quick, and reproducible, estimate of the carbohydrates in barley corresponding, in part, to those in spent grains; details of this method are given in Appendix I and results in Appendix II. Estimations of pentosan content (Kröber method) and crude fibre were made on a number of samples. In certain cases estimations were made of the cellulose content (method of S. H. Jenkins; *Biochem. J.*, 1930, 1428), lignin (strong sulphuric acid method), ash and fats. The primary data are given in Appendix II, together with determinations of moisture and nitrogen contents and thousand corn weights of the barleys and extracts of the corresponding malts by the Institute of Brewing Standard Method.

SECTION 2.

DISCUSSION.

As in the protein researches (L. R. Bishop, *loc. cit.*), it has been found with the carbohydrates that the regularities it is proposed to discuss hold much more accurately when quantities are calculated on a thousand corns* as a unit rather than on a hundred grams dry weight. With mature barleys the difference between the two methods is distinct but not

* Hemicellulose includes pentosans, hexosans and polyuronides which are soluble in mild alkali and hydrolysed by dilute acids as defined by:—

L. F. Hawley and A. G. Norman. (*J. Ind. and Eng. Chem.* 1932, 1190.)

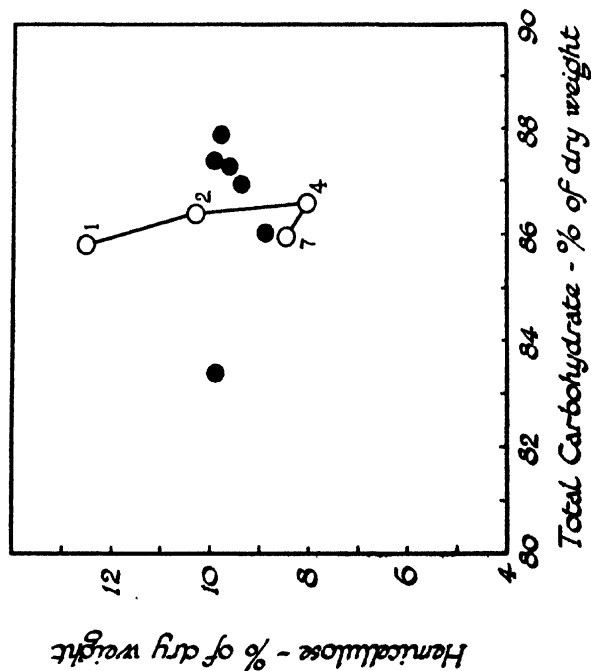
* The word corn is used instead of grain, since the latter may be confused with a unit of weight.

RELATION BETWEEN HEMICELLULOSE (PENTOSANS) AND TOTAL CARBOHYDRATE.

PLUMAGE-ARCHER BARLEY

○ - during development
● - mature samples

A



B

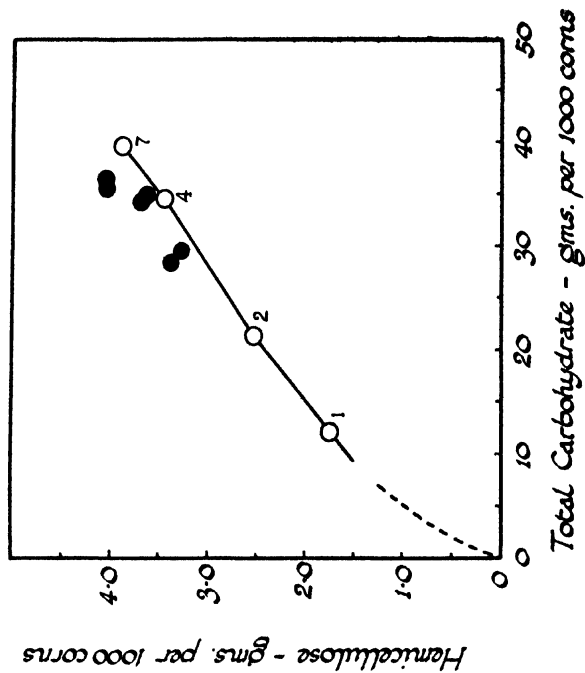


DIAGRAM I.

large, when, however, the wide range provided by immature barleys is taken into account the contention is proved, as is illustrated in Diagram 1. The same results plotted in (1a) on a dry weight basis show no relation, and in (1b) a regular relation on a thousand corn basis. So that, unless otherwise stated, comparisons will be made in this discussion on quantities of nitrogen or carbohydrate per thousand corns. It follows from these results, and similar ones for the proteins, that the natural plant unit is the individual corn, not a unit of weight such as a hundred grams, which is unnatural to the plant but is chosen because it is natural to the analyst.

In Diagram 1b quantities of pentosan (referred to here and in Diagram II as hemicellulose) have been plotted against the total carbohydrate. The latter figure has been obtained by difference: the quantity of protein present (nitrogen % $\times 6.0$) together with a constant 5 per cent. for ash and fats has been subtracted from 100 per cent. While this is not strictly accurate, it is close to the truth, and should there be in fact departures these would tend to mask the regularities which are nevertheless clearly shown in the following discussion.

Diagram 1b establishes the regular relation of pentosan to total carbohydrate in Plumage-Archer variety; for any given amount of total carbohydrate, there is a definite proportion in the form of pentosan both during development and at maturity. Data are given below which show that other carbohydrate constituents of Plumage-Archer show a regular relation to the total carbohydrate. It is also shown that similar regularities hold for other varieties, but although similar they are not identical and there are differences between the corresponding quantities in different varieties. The similarities in type of relation and quantitative differences between varieties are all the more interesting because they are closely comparable with the similarities and differences which have already been demonstrated among the proteins. (L. R. Bishop. *loc. cit.* and further work to be published). The main varietal difference in carbohydrate composition is that between two-row and six-row barleys. This is shown in Diagram II for a number of carbohydrate fractions of barley taking Plumage-Archer and Spratt-Archer as representatives of

two-row barleys and Atlas and F.112 of six-row barleys.

From the practical standpoint the carbohydrates of barley may be broadly divided into two groups (a) those which after malting and mashing produce extract and (b) those which do not.

They are:—(a) starch and sugars (b) cellulose and lignin. The hemicelluloses are to some extent rendered soluble.

The other empirical fractions measured are made up, as far as carbohydrates are concerned, from the following constituents of barley:—

Insoluble carbohydrate:—Cellulose and part of the lignin, Crude fibre:—chiefly cellulose.

Later on in the paper, the extract from a malt is assumed to be a measure of starch content in its barley. This is probably at least as true as the claim made by Schéele and Svensson (*Svenska Bryggare Foreningens*, 1927, 43 and 251) and earlier workers that the estimation of starch gives a measure of extract in the malt, an assumption which is the converse of that made in this paper. Either assumption is in agreement with the general "carbohydrate regularity" principle.

The results in Diagram 2 show that the various fractions of the carbohydrates which have been measured ascend regularly with the total carbohydrate and that there is a regular difference between two and six-rowed barleys. It is in these relations that the close and striking analogy with proteins is most clearly evident: a consideration of them however necessitates a comparison between carbohydrates and proteins.

ANALOGY BETWEEN THE PROTEINS AND CARBOHYDRATES OF CEREALS.

Individual proteins of the groups, albumin, globulin, glutelin and nucleoprotein, occur in the cells of most parts of nearly all plants and may be regarded as the normal cell proteins. Similarly, the carbohydrates, comprising sugars, hemicelluloses, cellulose and lignin are also normal cell constituents. On the other hand, the alcohol-soluble proteins are a distinctive group found only in cereal grains. They are insoluble in water and salt solutions, while as has been shown, they occur in greater amounts in barleys of higher nitrogen content, for instance in young developing Plumage-Archer grain three days after flowering only 5 per cent.

THE CARBOHYDRATES OF TWO-ROW AND SIX-ROW BARLEYS.

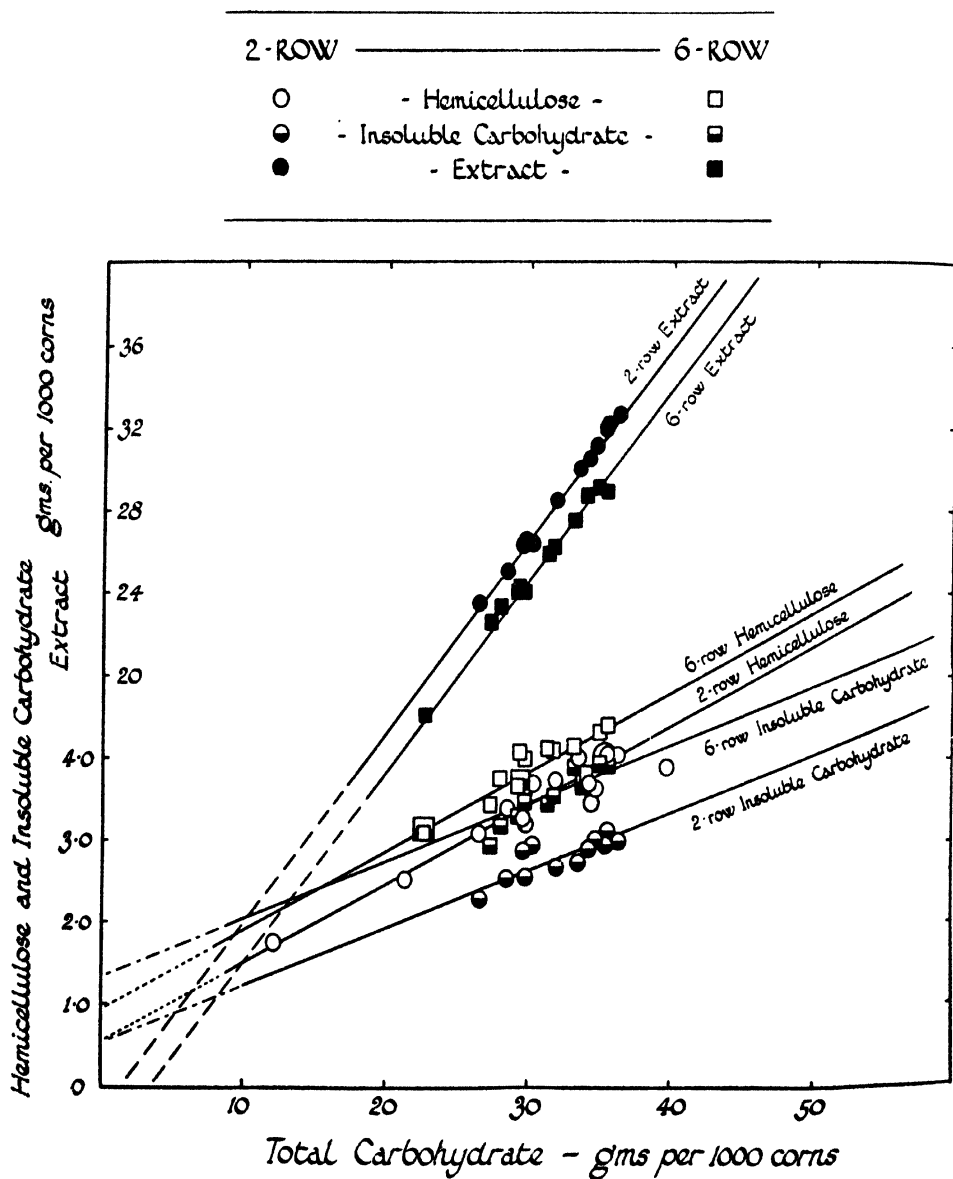


DIAGRAM II.

of the nitrogen was in the form of hordein while there was 40 per cent. in the highest nitrogen Plumage-Archer barley (Orwell Park, 1925) examined. In malting the chief source of nitrogen for the germ appears to be the alcohol-soluble protein nitrogen. The facts, therefore, suggest that the alcohol-soluble proteins function as reserve or storage proteins, as Beaven noticed (this *Journ.*, 1902, 561).

Starch, which is generally accepted as the storage carbohydrate, therefore corresponds to the alcohol-soluble proteins. The evidence given here suggests that, in exact agreement also, the proportion of starch, as measured by extract, increases with increase of the total quantity of carbohydrate, just as the percentage of hordein increases with increase

of total nitrogen. As more total carbohydrate, or protein, is available, so a greater proportion is converted to starch, or hordein, for storage and this increase takes place regularly.

The analogy with the proteins may be pressed still further for just as six-row varieties have a smaller proportion of their total nitrogen in the form of reserve hordein at any given total protein content, so these same varieties have a smaller proportion of reserve carbohydrate at any given total carbohydrate content.

These points are illustrated in Table I.

Whilst most of the protein data has been published before, in a different form, it is quoted here as it demonstrates the rise in hordein percentage with increasing total

TABLE 1.
CHANGES IN CARBOHYDRATE AND PROTEIN DISTRIBUTION WITH TOTAL QUANTITY.

Changes in Carbohydrate Distribution.						
Barley number.	Total Carbohydrate per 1000 corns. grms.	Percentages on Total Carbohydrate.				
		"Reserves."	"Cell Constituents."			
		Extract of malt.	Pentosan.	Insoluble Carbohydrate.	Crude Fibre.	Cellulose.
Two-row.						
Plumage-Archer (P) and Spratt-Archer (S.).						
P. dev. 1	12.1	—	14.5	—	—	12.5 ↑
P. dev. 2	21.3	—	11.8	—	—	10.4
S. 164 '28	26.5	88.0	11.5	8.6	7.1	—
P. 43 '23	28.5	87.5	11.9	8.9	—	—
P. 164c '28	29.6	88.7	11.0	9.7	7.5	—
S. 106c '30	29.8	88.8	10.7	8.6	—	—
S. 507 '28	30.3	86.1	12.1	9.6	—	—
S. 171 '27	31.9	89.3	11.7	8.3	6.8	—
S. 106c '29	32.5	89.4	12.0	8.2	6.6	—
P. dev. 4	34.2	—	10.1	—	—	10.0
P. 158c '25	34.2	89.0	10.8	8.4	—	—
P. 29 '23	34.7	89.5	10.3	8.6	—	—
S. 112c '30	35.4	90.0	11.3	8.3	—	—
P. 192c '28	35.5	90.5	11.4	8.8	—	—
Porlock '25	36.3	89.4	11.1	8.2	6.9	—
P. dev. 7	39.7	— ↓	9.8	—	—	8.6
Six-row.						
F. 112 (F.) and Atlas (A.).						
F. 144 '26	22.6	79.9	13.7	13.8	—	↑
F. 195c '27	27.2	82.8	12.6	10.7	9.6	—
F. 189c '27	28.0	83.4	13.3	11.3	8.5	—
F. 190c '27	29.2	82.2	12.6	11.3	8.7	—
A. 5 '31	29.3	82.7	13.9	12.7	—	—
A. 8 '31	29.6	81.1	13.4	11.6	—	—
F. 91 '29	31.3	82.2	13.1	11.0	8.5	—
A. 1 '31	31.7	82.5	12.8	11.2	—	—
A. 23 '31	33.1	82.8	12.5	11.8	—	—
F. 92 '29	34.0	84.1	11.2	10.9	—	—
A. 22 '31	34.9	83.2	12.3	11.3	—	—
A. 9 '31	35.5	83.6 ↓	12.4	11.0	—	—

Changes in Protein Distribution.

Number.	Total Nitrogen per 1000 corns. grm.	Percentages on Total Nitrogen.	
		"Reserves."	"Cell Proteins."
		Hordein.	Glutelin + salt soluble.

Two-row. Plumage-Archer (P) and Standwell (S.).			
P. dev. 1	0.216	5.1	94.9
P. dev. 2	0.354	18.2	81.8
Porlock '25	0.474	27.0	73.0
P. dev. 4	0.548	30.2	69.8
P. 15 '23	0.578	30.8	69.2
P. 17 '23	0.654	33.0	67.0
P. 60 '24	0.671	33.9	66.1
P. dev. 7	0.700	35.0	65.0
Orwell '25	0.872	39.5	60.5
S. C1 M.	0.941	39.7	60.3
S. C4 L.	1.060	40.6	59.4
S. C2 & 3 L.	1.118	42.7	57.3

Six-row.
F.112 (F), Atlas (A) and Vaughn (V).

F. 144 '26	0.288	19.1	80.9
A. 2 '31	0.348	23.0	77.0
A. 22 '31	0.378	24.6	75.4
F. 142c '27	0.443	23.0	77.0
F. 195c '27	0.460	22.8	77.2
F. 190c '27	0.532	25.6	74.4
F. B.5	0.664	27.4	72.6
A. 23 '31	0.780	30.2	69.8
V. 7 '31	0.879	35.5	64.5

In this table each barley is referred to by the year of growth and the same reference number as that used in previous reports in this series and in the "Ten Years' Report on the Barley Researches" (this "Journ.," 1933, 287). P. dev. nos. 1-7 refer to barley taken at various stages of development; for the carbohydrate analyses of these barleys we are very much indebted to Dr. A. G. Norman, F.I.C.

nitrogen* and the difference between two and six-rowed barleys.

It is evident from Table 1 that, similarly, with an increasing total carbohydrate content the percentage of extract rises, and that of cellulose and pentosan falls; further, that, at any given quantity of total carbohydrate, six-row barleys (compared with two-row)

yield less extract and contain correspondingly more pentosan, insoluble carbohydrate and crude fibre.

Having shown the broad difference between two and six-row varieties, the differences between individual varieties have next to be considered; do they differ significantly from one another, apart from the broad difference between two-row and six-row varieties? Here the limits of accuracy of most methods of estimation are approached, and it is necessary to resort to statistical methods to decide whether the small differences found are likely to be real or due to chance. The following table shows the results of such a study.

* It is hoped that at the same time two common misinterpretations of the protein results will be checked (a) that which translates the "regular relation of hordein to total nitrogen" into "a constant percentage of hordein on total nitrogen"; (b) that in which two-row barleys are stated to have a "higher percentage of hordein than six-row barleys" without the necessary qualification "at any given quantity of total nitrogen."

TABLE 2.

SIGNIFICANCE OF VARIETAL DIFFERENCES IN CARBOHYDRATE COMPOSITION.

Table of varietal constants in Equations of type:—

$$X = a + bT$$

Where a = the varietal constant, $X = H, I$ or E in grms. per 1,000 corns and T = total carbohydrate in grms. per 1,000 corns.

		Pentosan (H).	Standard Error.	Insoluble Carbo- hydrate (I).	Standard Error.	Extract (E).	Standard Error.
Two-row	Standwell	$a = +.5$	± 0.16	$+ .5$	± 0.14	$-.8$	± 0.34
	Spratt-Archer	$a = +.6$		$+ .5$		-1.3	
	Plumage-Archer	$a = +.5$		$+ .6$		-1.3	
	B-244	$a = -$		$+ .5$		-2.0	
Six-row	Indian ..	$a = +.9$	± 0.16	$+ 1.1$	± 0.14	-2.4	± 0.34
	F-112 ..	$a = +.9$		$+ 1.3$		-3.0	
	Atlas ..	$a = +1.0$		$+ 1.5$		-3.5	
	b all varieties ..	0.09626		0.0699		0.9300	

TABLE 3.

COMPOSITION OF THE INSOLUBLE CARBOHYDRATE AND OF SPENT GRAINS OF DIFFERENT VARIETIES.

	Ash.	Ether soluble.	Total dilute acid extract.	Lignin.	Acid- insoluble proteins.	Pento- sane.*	Cellu- lose.	Total.
As percentages on dry matter.								
Two-row malt spent grains	4.6	6.4	28.8	17.3	11.8	9.8	16.7	95.4
B-244 malt spent grains	5.6	5.1	34.0	15.5	11.2	8.5	16.3	96.2
Insoluble carbohydrate	1.0	8.0	4.5	10.7	0.8	3.9	62.7	91.6
Calculated back to original malt or barley as 100 per cent.								
Two-row malt spent grains	1.1	1.5	6.8	4.1	2.8	2.3	4.0	—
B-244 malt spent grains	1.6	1.4	9.4	4.3	3.2	2.4	4.5	—
Insoluble carbohydrate	0.1	0.6	0.3	0.8	0.1	0.3	4.7	—

* Apart from those included in acid extract and cellulose.

These results suggest it is possible that some two-row barley varieties differ from one another in their content of these carbohydrate groupings, but the differences are not significant. Similarly, there are insignificant differences among six-row barleys which are, nevertheless, consistent. The results given in Table 2 of a previous paper (L. R. Bishop and F. E. Day, this *Journ.*, 1933, 545) establish varietal differences in extract. There owing to the large number of analyses available the proof is definite; Standwell, for instance, is significantly higher in extract than Plumage-Archer and Spratt-Archer. And probably correlated with this is the fact that in the Table above Standwell is lower than the others in pentosan and insoluble carbohydrate contents. Similarly, among the six-row barleys, the order in all three sets of analyses is—Indian, F. 112, Atlas—which suggests that the observed differences are real.

While the results in Table 2 leave the question of individual varietal differences unsettled, they establish quite conclusively the broad difference between two-row and six-row barleys.

These results are regarded as placing on a firm basis what it is proposed to refer to as the "carbohydrate regularity principle," implying a regular relation between the individual carbohydrates and the total, a relation which is characteristic for each variety or group of varieties, but differs between them.

The whole of the evidence presented in an earlier paper (L. R. Bishop and F. E. Day, this *Journ.*, 1933, 545; Prediction of Extract II) is a further argument in favour of the carbohydrate regularity principle. There it was shown conclusively that each variety yields a quantity of extract which is constant, apart from

variations caused by protein content and thousand corn weight,* and that there are significant differences between the constants of different varieties. Confirmation of the principle is also to be found in a subsequent paper (this *Journ.*, 1934, 75), where it has been applied to a practical problem with successful results.

The special case of B.244, a two-row-six-row hybrid, merits attention. In its insoluble carbohydrate and its hordein content, it behaves like its two-row parent. As malt, its extract approaches, but falls short of that of the two-row barleys, while in its percentage of permanently soluble nitrogen and cold water extract it possesses six-row characters. Analyses suggest the probable reason why B.244 fails to come up

to the two-row standard in extract is that it has a higher content of some carbohydrate related to starch but not rendered soluble in mashing, and the variety probably corresponds to six-row varieties in this respect.

The evidence bearing on this is given in Table 3, which also brings out another point.

It will be seen from the upper part of the table that some 5 per cent. is not accounted for in these analyses, but the figures are closely comparable. New methods in preparation will considerably improve the absolute value of future figures, particularly those for lignin.

The lower part of the table shows that the insoluble carbohydrate fraction includes all of the cellulose and part of the fats and lignin of spent grains.

It was found that 21 per cent. of the two-rowed and 25 per cent. of the B.244 spent grains were soluble in boiling water, and that the main bulk of this extract was not pentosan or protein. It came, it is presumed, chiefly from carbohydrate which is soluble in boiling water or dilute acid, but is not rendered soluble by malt diastase. If B.244 has a higher proportion of this carbohydrate than have two-row barleys, the low extracts of the former variety are explained. Calculated on original malt, B.244 has 2.6 per cent. more of its spent grains soluble in boiling dilute acid than has the two-rowed spent grains, which corresponds to a lowering of 3.4 lb. in extract, while the average deviation of B.244 from its predicted extract was -3.3 lb.; this is because B.244 has a low insoluble carbohydrate content like that of two-row barleys.

This section may be summarised by stating that during development or at maturity each variety has a definite "carbohydrate pattern." When the quantity per corn (or per thousand corns) is taken as a unit, then with increasing total carbohydrate all the separate carbohydrates increase and increase regularly. The storage carbohydrates increase more rapidly than the "cell carbohydrates."* In two-row barleys

* With the carbohydrates the relations might be explained as the relation between internal volume of cells (starch) which would increase more rapidly than surface carbohydrates (cellulose, pentosan) if decided by physical factors only. On the other hand, this explanation will not deal with the proteins where microscopic examination shows all to be intimately associated. (L. R. Bishop, this *Journ.*, 1930, 336.)

* It may be noted here that the thousand corn weight factor is an approximate method of stating the rise in extract percentage with increasing total carbohydrate per corn since a heavier corn implies (generally speaking) more carbohydrate per corn (or per thousand corns). If extract increases accurately with total carbohydrate then formula (b) below should be more accurate than (a), which becomes an empirical first approximation to the same truth.

$$(a) E = A - bN + cG.$$

$$(b) E_4 = a_1 + b_1 T.$$

Where E_4 = grms. of extract per 1000 corns,

A and a_1 = variational constants,

b , c and b_1 represent the appropriate factors, and T = total carbohydrate in grams per thousand corns.

If equation (b) be converted to the usual units, it will be found that the reciprocal of G not G itself should be used.

For any 246 sample:—

$$E_4 = a_1 + b_1 T$$

$$= a_1 \times \frac{100}{G} \times \frac{1}{0.763} =$$

$$\frac{100 \times a_1}{.763} \times \frac{1}{G} + \frac{100b_1}{.763} \times \frac{T}{G}$$

which suggests that extract is a function of 1 and the G

percentage on dry weight of total carbohydrate. The latter decreases with increase of the nitrogen %.

Therefore E may be tested as a function of 1 and N %.

This was done with the "six variety" results and the following equations obtained:

$$(c) E = A - 10.20N + 0.176 G \dots \dots \pm 0.95.$$

$$(d) E = a_1 - 10.11N - 0.272 Z \dots \dots \pm 0.86.$$

Where (A) and (a_1) are variational constants and Z is the reciprocal of the average weight of a single corn (i.e., $\frac{1000}{G}$)

The expectations are fulfilled in that (d) is more accurate than (c) but the difference is not significant.

This accounts for the decreasing effect of increase of thousand corn weight in the higher ranges, which is noted in Prediction of Extract I (this *Journ.*, 1930, 421).

the storage carbohydrates regularly form a larger proportion of the whole than they do in six-row barleys.

In every respect the statements in the last paragraph are equally true if the word protein is substituted all the way through for carbohydrate. The full proof of this behaviour for proteins is available and will be published in a further paper. A generalisation of both sets of results is given in diagrammatic form in Diagram III.

Such behaviour is considered to support the view, advanced previously in connection with the proteins, that during the formation

of the grain there is a dynamic equilibrium of a mass action type between the different carbohydrates, through the intermediary of enzymes and simple sugars. With desiccation in the ripening grain the dynamic equilibrium becomes converted to a static one. Thus one curve will define the proportion to the total of any particular carbohydrate either during the development of an individual grain or in a set of mature samples of grain.

Varietal Individuality.

Recent work (L. R. Bishop and F. E. Day.

GENERALISED DIAGRAM OF CARBOHYDRATE AND PROTEIN RELATIONS AND INTER-RELATIONS.

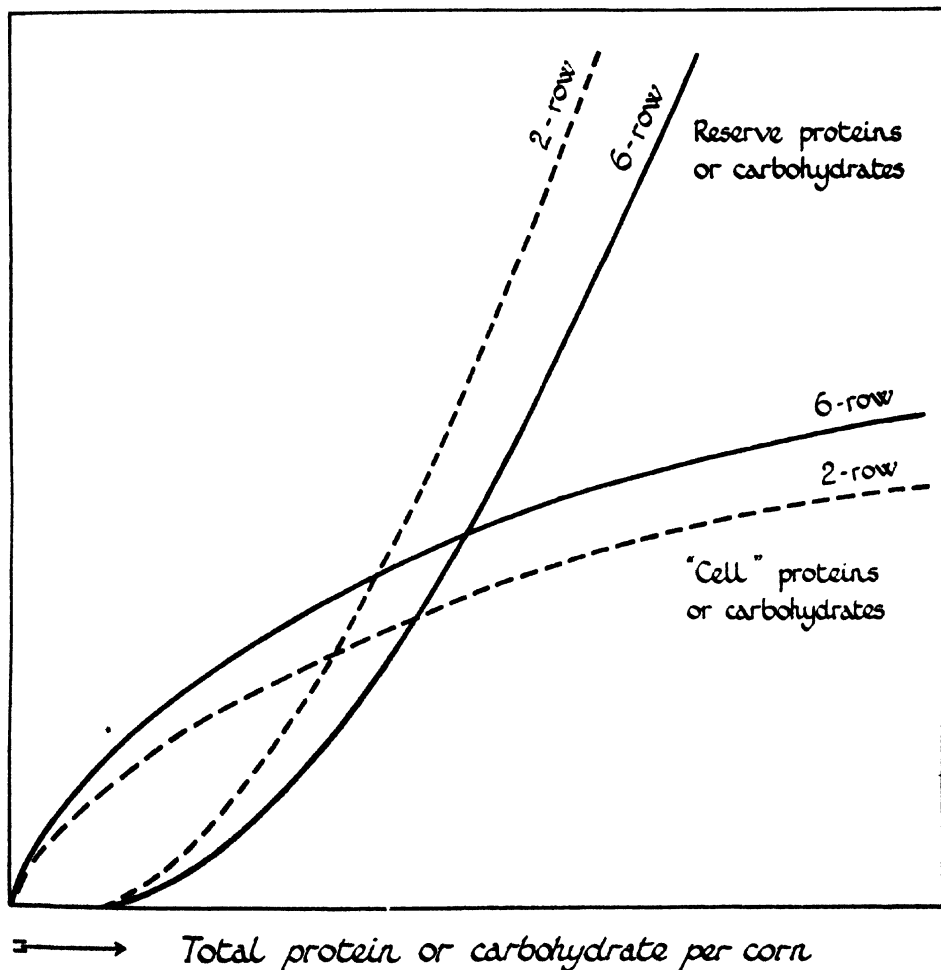


DIAGRAM III.

this *Journ.*, 1933, 545: E. J. Russell and L. R. Bishop, *ibid.* 287,) has done a good deal to clarify the biochemical characteristics of barley varieties and the insoluble carbohydrate and pentosan contents add to the list of properties of a barley grain, which, like the properties of a crystal, can be given as definite measurements characteristic of the variety. As we have seen the actual insoluble carbohydrate per 100 grms. dry weight varies with the thousand corn weight as well as with the variety, but that, if the insoluble and total carbohydrate are calculated as so many grams per thousand corns then the relation between the two is characteristic of the variety. For approximate purposes the insoluble carbohydrate may be given as a percentage of the total although the percentage varies somewhat with the latter. (See Table I.)

Table 4 gives the percentages of the insoluble carbohydrate measured in different varieties and the percentages of pentosan both on total carbohydrate and both for comparison with the extract constant which is similarly characteristic of the variety. As the insoluble carbohydrate and pentosan contents rise from variety to variety so the extracts decrease correspondingly.

An implication of this work is that there are similar small and regular differences in composition between the extracts of different varieties and that within each variety the carbohydrate composition of the extract is closely similar; this is, of course, apart from variations introduced by subsequent conditions, such as in mashing.

When this work was commenced, a study of the literature showed the prevailing ideas were that irregularity not regularity pre-

vailed in the barley grain. Metaphorically speaking, the barley grain was looked on as a householder whose income (of proteins and carbohydrates) was spent according to the dictates of fancy or the weather. Now the barley grain is to be looked on as the (economist's) ideal householder. Of the total income, a fixed proportion is expended on walls and lining (cellulose, hemicellulose and glutenin), strengthening material (lignin), available goods (sugars, albumin, globulin and proteoses) and a regular proportion is put in the bank for storage (starch and hordein). If the income is increased this efficient householder increases all allotments but more especially his reserves in the bank.

There is, however, one small qualification to these broad general statements for external conditions during and after harvest can probably do something, though not a lot, to affect the proportions of the carbohydrate and disturb the regularity. Statistical analysis of the data suggests that this occurs but that its effect is small. It is indicated also in Diagram 1b, which shows that developing barley is probably slightly lower in hemicellulose content than at maturity.

MALTING AND CARBOHYDRATE REGULARITY.

The analogy between the proteins and carbohydrates can be seen also in malting.

When the proteins are broken down they yield intermediate products (proteoses and peptones) and finally amino-acids. However the individual amino-acids do not accumulate to any great extent, instead, they are converted to asparagine which is a simple form of dipeptide. In an exactly analogous way the carbohydrates of barley are broken down to intermediate, and finally the simple, constituent sugars; here again these do not

TABLE 4.
VARIETAL CARBOHYDRATE CHARACTERISTICS.

Variety.	Insoluble Carbo- hydrate as percentage of Total Carbohydrate.	Pentosan as percentage of Total Carbohydrate.	Extract Constant. (A)*.
Standwell	8.3 ± 0.1	11.0 ± .1	109.7 ± 0.4
Spratt-Archer	8.6 ± 0.2	11.6 ± .2	108.6 ± 0.1
Plumage-Archer	8.8 ± 0.2	11.1 ± .2	108.3
Indian	11.1 ± 0.2	12.8 ± .3	104.8 ± 0.2
F-112	11.5 ± 0.4	12.8 ± .4	103.0 ± 0.3
Atlas	11.6 ± 0.1	12.9 ± .3	101.5 ± 0.3

$$\text{in equation } E = A - 10.5N + 0.2G.$$

accumulate, but are converted to a disaccharide—cane sugar. For instance, Loibl (Zeit. ges. Brau. 1923, 46, pp. 30, 37, 45, 61, 69), found during malting a rise of 5 per cent. in cane sugar, $2\frac{1}{2}$ per cent. in reducing sugars and a fall of $6\frac{1}{2}$ per cent. in starch.

Both in protein and in carbohydrate metabolism, Nature confronted by the multitudinous complexities of her own arrangements seems to choose one simple path from among the many possible.

Malt Analyses.

The carbohydrate regularity of different varieties suggests itself as the explanation of the varietal regularities seen in malt analyses. The cold water extract and the percentage of permanently soluble nitrogen are affected considerably by the physiological condition of the barley and the malting treatment, as has been shown, but these analyses also show a marked varietal individuality which suggests a carbohydrate effect. Below in Table 5 is given a list of the average insoluble carbohydrate, cold water extract and permanently soluble nitrogen of six examples of each of seven varieties malted in a comparable manner.

TABLE 5.

VARIETAL AVERAGES FOR INSOLUBLE CARBOHYDRATE, COLD WATER EXTRACT AND PERMANENTLY SOLUBLE NITROGEN.

	Insoluble Carbo-hydrate.*	Cold Water Extract.**	Permanently soluble Nitrogen.†
Two-row—			
Standwell ..	7.0	23	37
Spratt-Archer ..	7.4	20	35
Plumage-Archer ..	7.6	22	36
B.244	7.6	17	28
Six-row—			
Indian ..	9.5	20	29
F.112	9.9	20	32
Atlas	9.6	16	28

* Percentage on barley.

** Percentage on malt.

† Percentage on barley nitrogen.

At first sight the hypothesis suggests itself that the greater amount of insoluble carbohydrate, as cell walls, in six-row barleys retards enzymic attack during malting giving as a result lower cold water extract and permanently soluble nitrogen percentage.

However, the six-row \times two-row hybrid, B.244, shows that the story is probably not as simple as this; for, despite a low percentage of insoluble carbohydrate, it has a low percentage of cold water extract and permanently soluble nitrogen percentage.

Again, another possible explanation of the higher percentage of permanently soluble nitrogen in two-row barleys (compared with six-row) is as follows: Hordein is apparently (see L. R. Bishop, this *Journal*, 1929, 323) the chief protein broken down during malting and at any given total nitrogen content per thousand corns two-row barleys have more hordein than six-row and so should yield more permanently soluble nitrogen. This is an untenable explanation for two reasons. (a) Table 1 shows that high nitrogen six-row barley would be required to have a larger percentage of permanently soluble nitrogen than low nitrogen two-row barley, and (b) B.244, which has the high hordein content of two-row, yields the lower, six-row, permanently soluble nitrogen percentage.

We are very much indebted to A. G. Norman, D.Sc., F.I.C., and S. H. Jenkins, Ph.D., F.I.C., for advice on carbohydrate estimation methods.

SUMMARY.

In each variety the individual carbohydrates of barley grain increase regularly with the total carbohydrate. There are small differences between individual varieties which are more marked in the general distinction between two- and six-row barleys. The carbohydrates of extract ("reserve carbohydrates") increase more rapidly than the remaining carbohydrates ("cell carbohydrates") with increase of total carbohydrate. The unit on which these relations show most accurately is for quantities calculated at so much per corn (or per thousand corns).

In each of the above respects the behaviour of the carbohydrates parallels that of the proteins. Both suggest the regularities result from equilibria of a mass action type during development of the grain.

The similarity between the proteins and carbohydrates also holds in malting, during which the proteins are broken down to give asparagine and the carbohydrates to sucrose.

APPENDIX I.

I. METHODS FOR ESTIMATION OF
"INSOLUBLE CARBOHYDRATE."

The barley is first sieved and separated from fibrous contamination.

Grinding. The sample is ground in a Wiley mill with a 1 mm. sieve and the ground material very thoroughly mixed. It is necessary to break the material into small even lumps small enough to be easily attacked by the reagent but leaving a residue large enough to be retained by the filter without choking. This the Wiley mill with a 1 mm. sieve does successfully. An analysis by sieving of a typical sample showed the following distribution in particle size. (Table 6.)

TABLE 6.
PARTICLE SIZE BY TWO METHODS OF GRINDING.

	Wiley mill, 1 mm. sieve.	Coffee mill.
>2 mm.	0	5 per cent.
1-2 mm.	0	13 " "
0.5-1 mm.	55 per cent.	48 " "
0.1-0.5 mm.	32 " "	25 " "
<0.1 mm.	13 " "	9 " "

Trials of material ground in the ordinary coffee mill showed that duplicates do not agree so well as those from material ground in the Wiley mill.

The two essentials for accurate estimation appear to be :

1. Evenness of particle size in the ground material,
2. Accurate standardization of conditions, particularly of the rate of boiling.

Details of Method. A 5 gram. portion of the barley is weighed out, and transferred to a 500 cc. Kjeldahl flask. The neck of the flask is bound with asbestos string to protect

the hands from heat. Two hundred cc. of 0.5 per cent. sulphuric acid is brought to the boil under a reflux condenser, poured on to the barley with shaking to avoid lumps. The flask is fitted to another reflux and heated so as to cause it to boil in about 30 seconds. Steady boiling at a standard rate is continued for exactly ten minutes with occasional shaking. The flask is removed and 20 cc. of 9.50 per cent. sodium hydroxide solution (sp. gr. 1.100) added from a pipette, the flask being shaken meanwhile. This alkali neutralises the 0.5 per cent. acid and leaves 0.5 per cent. NaOH in the resulting 220 cc. of solution. The flask is put back under the reflux and brought to the boil. The whole operation of neutralising and bringing to the boil occupies one minute. Boiling is continued for exactly 10 minutes. The contents are filtered on double No. 41 Whatman filters on a Buchner funnel with suction. The flask is then rinsed out with hot distilled water on to the filter which is thoroughly washed by successive portions of hot water and allowed to suck dry.

The double filters have previously been cut to equal weight (± 0.0005 gram.) and area size larger than the funnel, e.g., 11 cm. papers on a 10 cm. funnel. They must be neatly fitted in.

The papers are dried in an electric oven for four hours* at 110°C. in a current of air, cooled in a desiccator and weighed with the second filter paper on the other pan of the balance. Duplicate analyses are made and the results calculated per 100 grms. dry matter.

Tests of the method showed it to give closely agreeing duplicates.

* Since this pre-drying with gentle heat on an electric hot plate has been used until "hand dry." One hour in the oven is then sufficient.

APPENDIX II.

TABLE 7.

ANALYSES OF BARLEYS AND MALTS STUDIED.

Analyses are on dry weight, and are the mean of duplicate determinations, except the pentosan figures and some of those for extract.

Barley.								Malt Extract.		
Variety.	Number.	Dry Matter %	Nitrogen %	1000 corn weight grams	Pen- tosan %	Crude fibre %	Insol- uble carbo- hydrate %	Anal- ysis	Predic- tion (1)*	Difference
Six Variety Set.										
Standwell	161, '25	86.80	1.37	42.2	9.2	5.44	7.07	102.6	102.6	0
	161, '26	87.76	1.69	38.5	9.9	5.6	7.12	100.8	99.6	+1.2
	161, '27	87.46	1.78	41.1	9.0	5.65	6.71	101.2	100.0	+1.2
	491-4, '28	90.67	2.12	46.4	9.3	5.74	7.18	96.8	95.6	+1.2
	140, '31	89.32	1.58	40.7	9.4	—	6.93	103.4	101.1	+2.3
	150, '31	88.56	1.92	54.6	9.2	—	7.08	100.1	97.6	+2.5
Spratt-Archer	171, '27	89.26	1.60	37.3	10.0	5.80	7.14	99.8	100.3	-0.7
	164, '28	88.17	1.34	30.5	10.0	6.2	7.50	100.4	101.7	-1.3
	507, '28	89.80	2.15	36.7	10.0	—	7.95	93.2	93.1	+0.1
	106c, '29	91.52	1.47	38.8	10.3	5.72	7.06	101.0	101.7	-0.7
	106c, '30	88.68	1.63	35.0	9.1	—	7.31	99.1	99.6	-0.5
	112c, '30	89.06	1.36	39.6	9.8	—	7.20	102.3	102.3	0
Plumage-Archer	29, '23	87.66	1.49	40.3	8.8	—	7.44	100.9	100.5	+0.4
	43, '23	87.44	1.94	34.2	9.9	—	7.44	95.7	96.5	-0.8
	Porlock '25	87.86	1.18	41.3	9.8	6.02	7.24	104.0	103.8	-0.8
	158c, '25	88.00	1.35	43.5	9.4	5.63	7.36	101.4	102.0	-0.6
	164c, '28	88.50	1.28	33.9	9.6	6.55	8.41	101.4	99.6	+1.8
	192c, '28	88.50	1.27	40.6	9.9	—	7.68	103.6	101.8	+1.8
Indian	1, '29	88.94	1.18	33.4	11.2	—	9.28	99.8	98.1	+1.7
	10, '29	89.02	1.58	29.8	11.2	6.89	9.36	96.1	96.1	0
	18, '29	92.04	2.05	29.2	11.3	—	10.06	87.4	88.1	-0.7
	19, '29	89.56	1.52	35.4	10.4	7.08	8.91	95.3	96.1	-0.8
	21, '29	89.68	1.24	28.3	10.5	—	10.11	96.0	95.2	+0.8
	23, '29	89.56	1.32	35.3	11.3	7.06	9.52	98.1	96.2	+1.9
F.112	144, '26	88.22	1.40	26.1	11.8	—	11.92	90.7	88.4	+2.3
	189c, '27	89.78	1.48	32.8	11.8	7.35	9.72	94.1	94.2	-0.5
	190c, '27	88.04	1.53	34.0	10.8	7.50	9.68	92.4	93.3	-0.9
	195c, '27	87.06	1.30	31.2	11.0	8.38	9.37	94.6	97.2	-2.6
	91, '29	87.86	1.38	36.1	11.4	7.35	9.52	93.5	95.5	-2.0
	92, '29	88.78	1.29	39.0	9.8	—	9.47	96.2	96.6	-0.4
Atlas	1, '31	87.58	1.40	36.6	11.1	—	9.71	93.6	95.0	-1.4
	5, '31	87.90	1.57	34.2	11.9	—	9.71	92.8	93.4	-0.6
	8, '31	87.70	1.80	35.2	11.3	—	9.72	89.5	91.1	-1.6
	9, '31	87.92	1.42	41.1	10.7	—	9.55	94.8	94.9	-0.1
	22, '31	87.70	1.28	40.0	10.8	—	9.84	95.2	95.8	-0.6
	23, '31	88.60	1.89	39.5	10.5	—	9.10	90.8	92.2	-1.4

* From Equation (1) in a subsequent paper (Prediction of Extract III, this *Journ.*, 1934, 81)

*Rothamsted Experimental Station,
Harpenden,
Herts.,
22nd December, 1933.*

THE INSTITUTE OF BREWING RESEARCH SCHEME.

PREDICTION OF EXTRACT III.

APPLICATION OF THE CARBOHYDRATE REGULARITY PRINCIPLE.

By L. R. BISHOP, M.A., Ph.D.

THE extract which a barley will yield when made into malt is frequently estimated on the Continent by measuring the extract obtained from the barley; this has some disadvantages.* It is evident that, were it possible, isolation and weighing of the complementary fraction, the "spent grains" of barley, would be an equally satisfactory method but it would probably take as long. The carbohydrate regularity principle, L. R. Bishop and D. Marx (this *Journ.* 1934, 62) suggests that a quick modification is possible.

The earlier method for extract prediction, (L. R. Bishop, *ibid.* 1930, 421; L. R. Bishop and F. E. Day, *ibid.* 1933, 545), virtually amounts to estimating the spent grains. For, in each variety, at any given thousand corn weight the "spent grains carbohydrates" are constant in amount. The variable is the quantity of protein in spent grains together with some carbohydrate which this protein has "sealed up"; it is, therefore, possible to estimate the extract by subtracting from the varietal constant a variable quantity equal to the protein and the carbohydrate it "seals up."

This method is satisfactory provided that the variety of the barley and its characteristic constant are known. Often, however, in practice this is not the case, as barley samples are usually of mixed or unknown origin. With these the carbohydrates of spent grain are variable as well as the proteins and clearly from an estimate of both variables a satisfactory method of extract calculation would result. This would have the distinctive

advantage that it could be applied to any sample of barley, irrespective of its variety.

Such carbohydrate estimations are available but are also lengthy and involved. The "carbohydrate regularity" principle, however, suggests a quicker solution of the problem, for it should be possible to measure a definite fraction of the carbohydrates of spent grain which would bear a regular relation to the total and the problem of estimating the extract of any barley sample would be solved. This is what the "insoluble carbohydrate" estimation attempts to do. In it, the varying effects of the proteins and of the carbohydrates of spent grains are measured separately and then added together to estimate the quantity of spent grains and so the extract.

One further possibility is to measure the effects of the carbohydrates and proteins of spent grains in one estimation. This has been attempted in an "insoluble fraction" method which is not sufficiently accurate, though it may prove capable of improvement

SECTION I.

METHODS AND RESULTS.

The method for the estimation of the "insoluble carbohydrate" has been given in a previous paper (this *Journal*, 1934, 62), it has been applied to 209 barleys of a wide range of origin and character. On the same barleys determinations have been made of nitrogen, moisture and thousand corn weight. The extracts of the corresponding malts have also been determined. The results are given in Appendix II. A short summary of the statistical treatment of the results is given in Appendix I.

A test has also been made of a method based on the estimation of an "insoluble fraction." The details of this method are given in Section 5, page 84.

* The methods used are complicated and that of Seibriger is stated to take 24 hours by Schéele and Svenson (*Svenska Bryggare Föreningens* 1929, 41.). Further, Steenhof (*ibid.*, 1927, 171) has shown that in order to obtain accurate results it is necessary to determine the nitrogen content as well.

SECTION 2.

DISCUSSION.

(a) *Test with six representative varieties.*

The first test made, was to apply the insoluble carbohydrate method to six samples of each of six varieties. Both the samples and varieties were selected to give as wide

a range as possible in extract, the extreme range being 87.4 to 103.6 lb. The method was found to work very well, as is demonstrated in the following diagram.

*This very useful type of diagram was devised by Dr. E. M. Crowther, F.I.C.; it allows diagrams to be drawn illustrating the relation between three quantities; this previously needed a solid model.

SIX VARIETY EQUATION FOR EXTRACT PREDICTION.

$$E = 136.7 - 8.34N - 3.17I$$

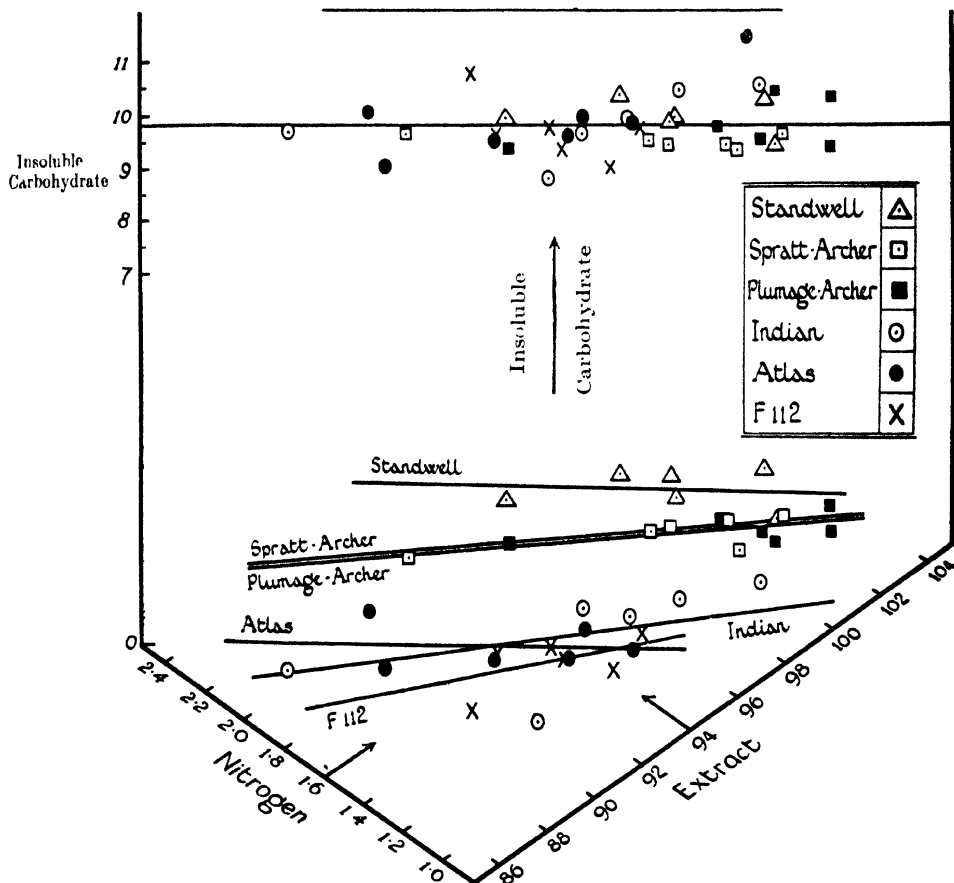


DIAGRAM I.

In Diagram 1* the extract is plotted against the nitrogen content on two axes inclined at 120° instead of the usual 90°. The points at the bottom of the diagram show the relation between nitrogen and extract and the large differences between different varieties. This part of the diagram corresponds to the diagram in a previous paper (L. R. Bishop and F. E. Day, this *Journ.*, 1933, 545). The present method of plotting, however, allows of the addition to each point of a height corresponding to the weight of insoluble carbohydrate obtained. Then, since the low extract varieties yield larger amounts of insoluble carbohydrate and the high extract ones less, the points are all brought close to one line at the top of the diagram. The closeness of approach to this line affords visual proof of the accuracy of the two factors, nitrogen content and insoluble carbohydrate, in accounting for the extracts of the malts.

Together, nitrogen and insoluble carbohydrate account for 91 per cent. of the variation† in extract; the 9 per cent. (error) unaccounted for was found to be much smaller than in any other of the extract calculation methods tried; and the insoluble carbohydrate content alone, proved considerably more accurate than nitrogen content and thousand corn weight, when no

allowance was made for the separate varietal characteristics. The relative accuracy is shown in the following diagram (Diagram 2).

The standard error of calculations from nitrogen and insoluble carbohydrate content is still high (± 1.3 lb.) but this is partly

† This word is used instead of the correct statistical term which is variance.

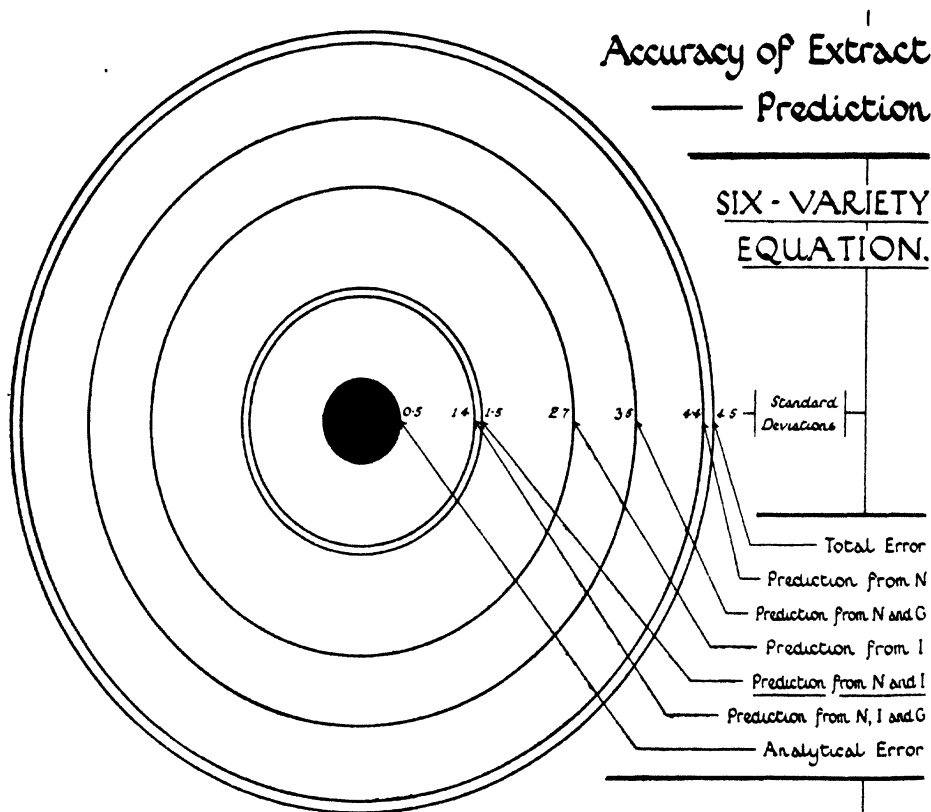


DIAGRAM II.

Attempts to measure the extract, whether by prediction or by analysis, may be represented as marksmen's shots aimed at the centre of the bull's-eye of a target. All of the shots are subject to errors and, as in every type of measurement, some individuals are, by chance, more in error than others. A circle can, however, be drawn (with a radius proportional to the standard error) which includes 68 per cent. of the shots. Then the area of this circle (proportional to the square of the standard error) is a measure of the variation (variance) of the results.

This has been done in Diagram 2, where the size of circles shows the closeness with which calculations from the different factors approach the blackened "bull" representing the errors of the analyst in determining the extract. Calculation from the nitrogen content and percentage of insoluble carbohydrate gives the most accurate predictions, and the addition of a factor for the thousand corn weight does nothing to improve the accuracy.

due to the wide range in the physiological condition of the barleys at malting and possibly to variation in the malting treatment. The effect of these factors can be measured by the percentage (P) of the total barley nitrogen becoming permanently soluble in the wort. With this factor taken into account as well the standard error is reduced from ± 1.3 lb. to ± 1.1 lb. The errors still remaining are almost entirely due to some varietal factor still unaccounted for. When this is allowed for by a constant difference between each pair of the varieties the standard error is reduced to the very low figure of ± 0.45 lb. and this remainder may be safely attributed to experimental errors. The equation giving this very accurate result is:—

$$(3) E = a + 0.1086G + 0.223 P - 1.5 I - 9.03 N.$$

Where "a" is a constant depending on the

variety. This equation is comparable with $E = A - 10.20N + 0.176G$, which has a standard error of ± 0.95 lb. This equation shows that "I" has a small effect in each variety apart from thousand corn weight. This probably implies, as previously mentioned, that the regularity principle is not absolute but that small varieties in carbohydrate composition occur as the result of seasonal influences.

(b) *Practical Tests with English Two-Rowed Barleys.*

The question next arose as to how closely such extract calculations hold under commercial conditions. By the kindness of Edward Sutcliffe, Ltd., a number (104) of English barleys were received, together with their analyses as malt and details of temperature and time on the floor and kiln.

The barleys were ordinary commercial samples of unknown variety but a study

ACCURACY OF EXTRACT PREDICTIONS.

COMMERCIAL ENGLISH TWO-ROW BARLEYS

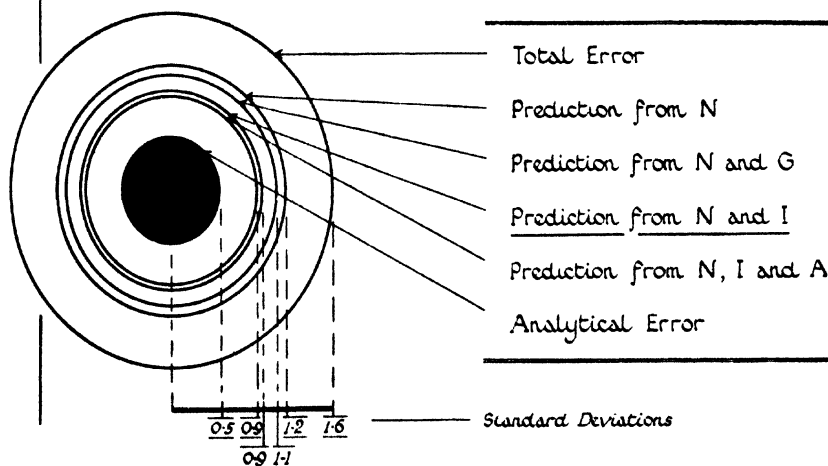


DIAGRAM III.

In Diagram 3, as in Diagram 2, the areas included by the circles are proportional to the errors of extract calculated from the factors named. In order of decreasing accuracy these are nitrogen and insoluble carbohydrate content, followed by nitrogen and thousand corn weight, while nitrogen content alone is slightly more inaccurate. The superiority of nitrogen and insoluble carbohydrate content calculations over those from nitrogen and thousand corn weight, although small, is large enough to be undoubtedly significant.

of the results showed that, when considered from the point of view of extract yield, these English barleys nearly all behaved as one variety, with an average close to that found for Plumage-Archer. The original equation given for this variety (L. R. Bishop, this *Journ.* 1930, 421) was found to fit the results very well (the standard error was ± 1.1) and the average difference from it was only $+ 0.03$ lb. W. J. Mitchell (this *Journ.*, 1932, 241) has shown that this equation holds for Scottish barleys also. Nevertheless there are varieties of two-rowed barleys differing considerably from Plumage-Archer in their extract yields for any given nitrogen content (L. R. Bishop and F. E. Day, this *Journ.*, 1933, 545). Some representatives of such varieties must have been included in this set, so that when barley nitrogen and insoluble carbohydrate contents are taken, the extracts can be calculated more accurately. This is shown by the standard errors of the two : that for nitrogen content and thousand

corn weight is ± 1.1 , while that for nitrogen content and insoluble carbohydrate is ± 0.9 which corresponds to a 10 per cent. increase in accuracy; an improvement which is significant statistically but may not be large enough to justify the use of the method in practice, especially as English barleys are usually bought in small lots. The relative accuracy of the different calculation methods is shown in Diagram 3.

(c) *Practical Tests with Californian Six-Rowed Barleys.*

Californian barleys on the other hand are bought in large quantities, varietal differences in extract are larger and mixtures often occur. Consequently an extract equation eliminating varietal effects promises to be of more use and such has actually been found to be the case. 47 samples and data relating to them were supplied by Messrs. Hugh Baird and Sons.

The results showed that calculations from

ACCURACY OF EXTRACT PREDICTIONS.

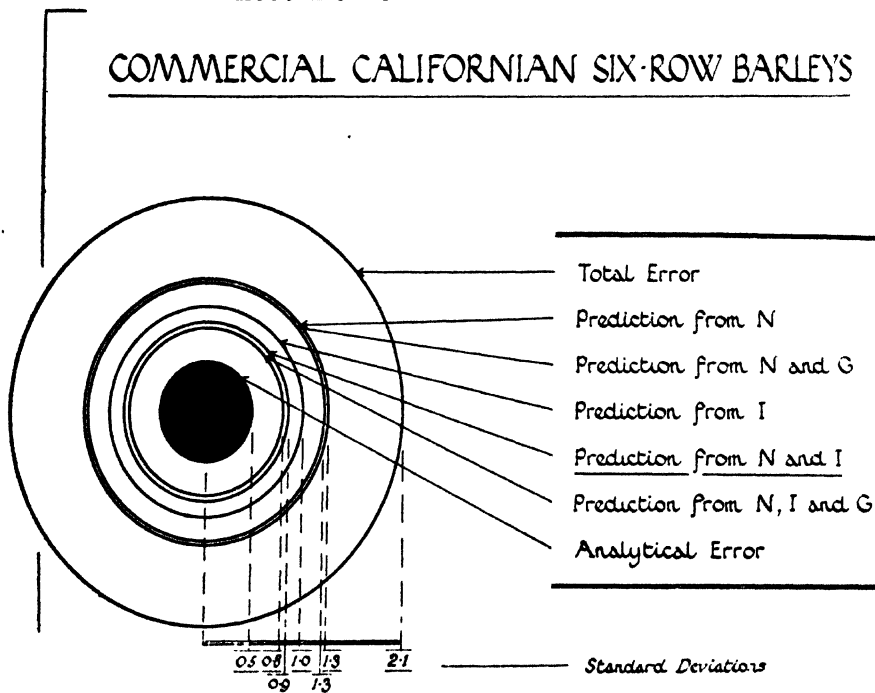


DIAGRAM IV.

The total variability in extract is greater here than with the English two-rowed barleys and the distinctly smaller circles show the marked superiority of insoluble carbohydrate content alone, and still more in conjunction with nitrogen content over nitrogen and thousand corn weight, as a means of calculating the extract.

the nitrogen content and thousand corn weight accounted for 64 per cent. of the variation in extract (standard error ± 1.3 lb.), that the insoluble carbohydrate alone accounted for 76 per cent., and together with nitrogen content for 83 per cent. of the variation; the standard error for calculations from the latter two (N and I) was ± 0.9 lb. and again, no improvement was effected by considering the thousand corn weight in addition. The relative accuracy of the equations is shown in Diagram 4.

Through the kindness of Hugh Baird and Sons, it was possible to make a short study of the barleys of the previous year. A set of Californian barleys of known varieties supplied by the United States Department of Agriculture, was also studied. Both these sets confirmed the conclusion that nitrogen content and insoluble carbohydrate give, irrespective of variety, a reliable guide to the extracts which Californian barleys will yield as malts.

(d) *Combining the results from the Two-Rowed and Six-Rowed Barleys.*

As a further test of the method the results from the two sets of commercial barleys (English two-rowed and Californian six-rowed) were put together and the extracts calculated from the derived equation. Here the varietal differences were considerable. The extreme range was 102.8 to 91.0 lb. and the means of the two sets were 100.2 and 94.5 lb. In consequence of the large varietal differences, nitrogen, or nitrogen and thousand corn weight, proved very inaccurate in accounting for the extracts. The standard error of the N and G calculations was ± 2.1 lb. and they accounted for only 56 per cent. of the variation. The insoluble carbohydrate alone had a much smaller standard error (± 1.3 lb.) and accounted for 84 per cent. of the variation. On the other hand, the nitrogen content and insoluble carbohydrate predicted the extracts with the same error as for the individual sets (± 0.9 lb.)

ACCURACY OF EXTRACT PREDICTIONS.

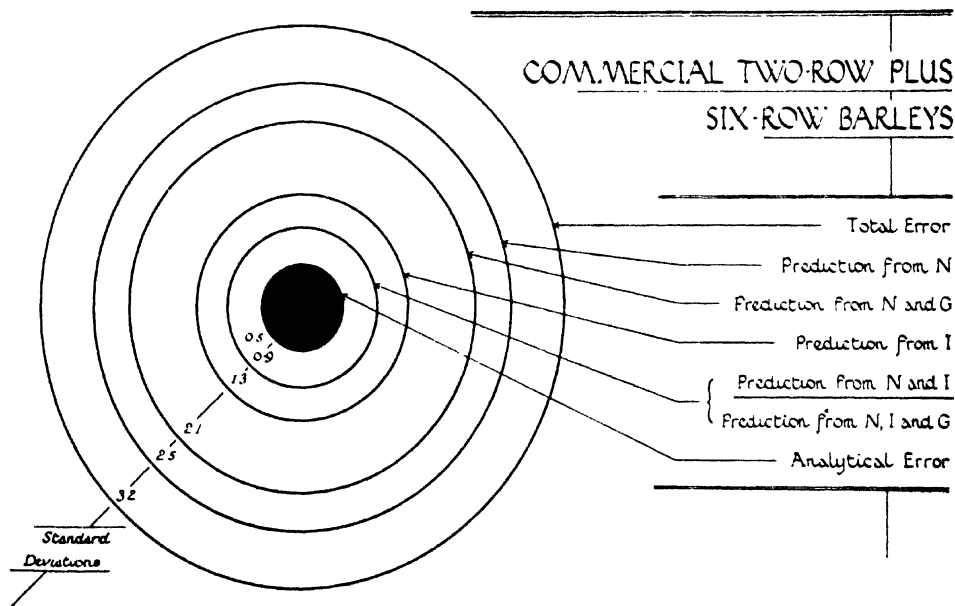


DIAGRAM V.

The relative accuracy of the different extract predictions is illustrated in Diagram 5.

EXTRACT PREDICTION—TWO-ROW PLUS SIX-ROW RESULTS.

GIVING ALTERNATE CASES ONLY IN TWO-ROW.

$$E = 134.7 - 9.78N - 2.64I$$

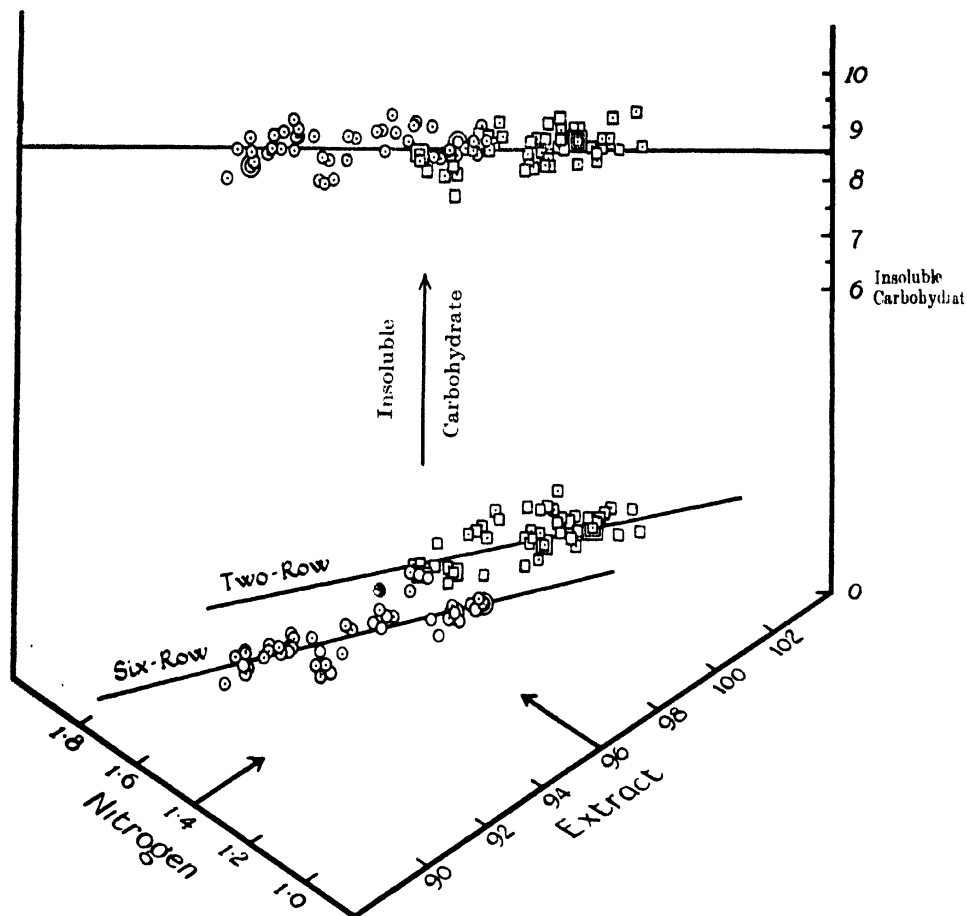


DIAGRAM VI.

Diagram VI makes it clear that the large varietal differences between English and Californian extract yields are completely accounted for by the differences in their carbohydrate composition, as measured by the "insoluble carbohydrate" estimation.

and accounted for 92 per cent. of the variation in extract.

3. CALCULATION OF A "RESTRICTED GENERAL EQUATION."

All the results were combined and one equation calculated from them. They were from the six varieties (Standwell, Spratt-Archer, Plumage-Archer, Indian, F. 112 and Atlas), the commercial two-row and the

commercial six-row samples. Equation (1), i.e.,

(1) . . . $E = 134.7 - 9.0N - 2.8I$. . . held accurately for the 187 samples, and the standard error was ± 1.0 lb.

The results from six barley varieties came from stocking maltings, while the commercial barleys and malts represented ordinary bulk maltings. The fact that the standard error was not appreciably increased

shows that no disharmony exists between the two. The equation therefore appears to be of fairly general application, although, as shown, the predictions for certain varieties are not very accurate, and the equation has, therefore, been styled a "restricted general equation." It has the same uses as the specific varietal equations given in an earlier paper (L. R. Bishop and F. E. Day, this *Journ.*, 1933, 545), with the added advantage that it can be applied to samples which are of mixed or unknown varietal origin. It would appear to be most useful with Californian samples. The uses are (a) as an aid in buying barleys, (b) as a check on the efficiency of the malting method, (c) as a check on the accuracy of the extract determination, (d) for use in the breeding of new varieties.

VARIETAL IRREGULARITIES.

One or two of the six varieties studied showed evidence of small regular deviations between calculated and observed extracts and larger divergences were noted in a few among several odd samples of other varieties. Figures for these samples are given in Table I.

Most varieties appear to agree well, but

there are striking exceptions in the case of one sample of Trebi, and regular exceptions in the case of variety B-244 (a new variety bred at Cambridge). Although this variety gives a high extract for a six-rowed barley, yet the calculation predicts a higher extract still. The probable explanation of these divergences is that the insoluble carbohydrate, as here determined, includes only part of the carbohydrate remaining insoluble in the spent grains of the malt. In most varieties the proportion is similar between the fractions included in and omitted from this estimation. However, the underlying hypothesis is not invalidated, in fact it would suggest that certain varieties would regularly have a different proportion between the measured and the total insoluble carbohydrate.

4. SIGNIFICANCE OF THE FACTORS IN THE GENERAL EQUATION.

It is usually assumed, as Haase (*Woch. Brau.*, 1906, 23, 35) suggested, that the lowering of extract by nitrogen is due simply to insoluble protein replacing carbohydrate in the grain in equivalent amounts. Four years before Beaven (this *Journ.*, 1902, 558) calculated the effect of nitrogen but gave no

TABLE I.

APPLICATION OF RESTRICTED GENERAL EQUATION (1) TO OTHER VARIETIES.

Barley No.	Year.	Variety.	Predicted Extract (1).	Extracts on analysis.	Difference.	Varietal Average.
—	—	July	100.6	101.2	+ .6	—
—	1928	O.A.C. 21	90.8	92.1	+1.3	—
9 & 10	1928	} Trebi	95.4	94.3	—1.1	} —2.6
	1930		93.6	87.9	—5.7	
	1932		96.7	95.8	— .9	
9 & 10	1931	Californian (variety unknown)	96.0	96.5	+ .5	—
	1926	Hero	89.1	86.2	—2.9	—
7	1931	Vaughn	88.1	83.5	—4.6	—
	1926	} Tennessee Winter	86.0	87.2	+ 1.2	—
2	1931		96.8	97.3	+ .5	—
11	1931		94.6	94.0	— .6	—
	1926	} Mariout	87.6	87.5	— .1	—
24	1931		96.1	94.8	—1.3	—
	1926		84.3	86.8	+2.5	—
	1926	Smooth Awn	92.2	89.4	—2.8	—
199	1927	} B.244	98.6	94.6	—4.0	} —3.3
200c	1928		100.6	99.2	—1.4	
131	1929		97.2	94.0	—3.2	
110c	1930		102.2	98.7	—3.5	
111c	1930		101.6	98.1	—3.5	
115c	1930		101.2	97.4	—3.8	
116c	1930		100.9	97.5	—3.4	

equation as he realised qualitatively the effect of other factors, such as husk and modification.

The results given here show that simple replacement of carbohydrates by protein can be only a partial explanation, and there is no doubt that some other effect comes into play. In Appendix I. the actual stages are given by which, for comparison with that actually obtained, an equation is derived on the simple protein replacement hypothesis. In this comparison equation (1) has been converted to give "true" extract as a percentage on dry malt. The "true" extract has been obtained by incorporating a correction for the fact that, in the Institute Standard Method, a constant 15 ccs. is allowed for the volume of the grains, whereas in actual fact the volume varies inversely with the extract. The two equations are:—

Actual equation

$$E_a = 104.6 - 7.27N - 2.23I.$$

Expected equation

$$E_s = 104.2 - 4.38N - 1.04 \text{ (true insoluble carbohydrate).}$$

Where E_s is the "true" extract as a percentage on dry malt.

The agreement between the constants (104.2 and 104.6) is close, but the actual nitrogen factor (7.27) is nearly twice as large as that expected on the protein replacement hypothesis (4.38), showing that another effect comes into play which may be explained as follows: the extracts were determined by the Institute Standard Method in which the malt is ground in a roller mill with $\frac{1}{2}$ mm. gap between the rolls. With this degree of grinding, some of the potentially soluble carbohydrate is probably "sealed up" in a protein matrix, and this effect increases with increasing nitrogen content. This was shown by comparing the extracts obtained by the standard and by fine grinding from the same malts (Calculated from data of H. Lloyd Hind, this *Journ.*, 1924, 971). With fine grinding more extract was obtained, particularly from the high nitrogen malts, and the nitrogen factor for fine grinding (-4.9) approaches that suggested by the simple protein replacement hypothesis.

The insoluble carbohydrate factor, which should approximate to 1.0, is also much larger (2.23). This is partly explained by the fact already mentioned, that the present method of estimation measures only about

half the insoluble carbohydrate corresponding to that in spent grains. The method includes all of the cellulose, but only part of the hemicellulose and lignin of spent grains (see L. R. Bishop and D. Marx, this *Journ.*, 1934, 62). Since the individual carbohydrates are regularly related to the total quantity for each variety in proportions which are similar in most varieties, it is usually sufficient to measure this proportion of the whole and multiply by a constant factor for all varieties. With some varieties, e.g., B.244, the factor required is rather different and this leads to a certain amount of systematic error.

The figures obtained were subjected to a detailed statistical analysis in order to analyse out the effect and interaction of the factors, nitrogen, thousand corn weight and insoluble carbohydrate (see Appendix I p. 86); and the following conclusions were reached.

(a) That nitrogen, alone or with thousand corn weight, is only of use in calculating the extract within the limits of each variety separately. Here, as shown above, its effect is due to the replacement of carbohydrate by insoluble protein, with the further effect that in coarse grinding higher nitrogen is associated with a greater "sealing up" of potentially soluble carbohydrate.

(b) In all varieties the thousand corn weight plays the same part which, as has previously been suggested, may be due to the smaller proportion of insoluble husk in heavier grain. This view is supported by other results given here, since the insoluble carbohydrate, a large part of which comes from the husk, is found to be inversely related to the grain weight.

(c) Insoluble carbohydrate successfully accounts for much of the difference in extract which exists between varieties. This shows that it is owing to differences in their carbohydrate composition that varieties differ in extract yield, the effect of nitrogen being the same for all varieties. The analysis reveals that besides accounting for the differences between varieties, the insoluble carbohydrate estimation accounts also for the small differences between samples of the same variety which are partly produced by thousand corn weight. Consequently, there is little advantage in taking into account the latter as well as insoluble carbohydrate and nitrogen content when calculating extract.

It was found that the nitrogen content varies independently of the insoluble carbohydrate, implying that high nitrogen is not associated with heavier husk, since the insoluble carbohydrate comes mainly from the latter. It follows that what the buyer recognises as "coarse skin" in high nitrogen barleys does not imply a thicker or heavier husk, so that the present results afford confirmation of the similar lack of relation found by Horace Brown, (*Trans. Guin. Research Lab.* 1903-06, p. 134) from direct measurements of husk thickness.

On the other hand the direct effect on extract of the differing huskiness of different varieties of barley has long been recognised. The present study confirms the existence of this by measuring it accurately and shows that it is directly associated with the characteristics of the different varieties.

SECTION 5.

THE TOTAL INSOLUBLE FRACTION ESTIMATION.

As mentioned in the introductory paragraphs of this paper, the possibility exists of measuring the effects of both protein and carbohydrate on extract in one estimation and the accuracy of one of the possible methods for this has been investigated.

The method used was similar to that for the "insoluble carbohydrate" estimation, except that only one extraction was made with a boiling solution containing 10 per cent. calcium chloride and $\frac{1}{2}$ per cent. hydrochloric acid. This was boiled at a definite steady rate continued for exactly ten minutes, and the insoluble fraction filtered off on balanced filter papers, washed, dried and weighed as in the "insoluble carbohydrate" method. Results can be obtained in 2-3 hours after receiving a sample.

A wide range of barleys was used to test the method. Analysis of the data shows that it is not as accurate as other methods for predicting extract.

The equation obtained was :—

$$(2) E = 138.7 - 2.3 F \dots \pm 1.9 \text{ (n=57).}$$

Where F=percentage of insoluble fraction on dry barley.

This is too inaccurate for practical use, and is given only as a suggestion of further possibilities.

The insoluble fraction averages 70 per cent. of the spent grains which it estimates,

but it was found that a modification of the method gave results almost identical with the corresponding weight of spent grains. The modification consisted in the substitution of $\frac{1}{2}$ per cent. lactic acid for the $\frac{1}{2}$ per cent. of hydrochloric acid in the extracting solution. However, the residues filtered slowly, and the accuracy was no greater, as the same defect was found in both. This defect is similar to and probably an exaggeration of that found in the "insoluble carbohydrate" method, which, it will be recalled, extracts a certain type of carbohydrate which remains insoluble under enzyme action in mashing. As a result, B-244 gives a smaller and Standwell a greater residue than they "should" in both methods.

The method given was selected after extensive trials of various salts, acids, etc., as peptising agents for the carbohydrates of extract.

I have very much pleasure in thanking the following who have given invaluable assistance in this investigation :—

Hugh Baird & Sons, Ltd., Edward Sutcliffe, Ltd., the National Institute of Agricultural Botany, and Messrs. Arthur Guinness, Son & Co., Ltd. who have supplied barleys and malts. Also

Mr. S. F. Weeden, Mr. G. D. Clarkson, Mr. F. E. Day, B.Sc., F.I.C., and Miss D. Marx, M.Sc., who have supplied figures and analyses, and those members of the staff at Rothamsted who have assisted in the statistical interpretation of the results.

SUMMARY.

The carbohydrate regularity principle has been applied to give practical results in the form of an extract prediction equation, which can be used where the variety of the barley is unknown—a common position in practice. It appears to be particularly accurate and useful with Californian barleys.

The equation for this calculation is :—

$$E = 134.7 - 9.0 N - 2.8 I \dots \pm 1.0 \text{ lb.}$$

Where E=brewers' lb. of extract per quarter of dry malt, determined by the Institute of Brewing Standard Method.

N=nitrogen percentage on dry barley.

I=percentage of "insoluble carbohydrate" on dry barley.

The equation can be converted to give extract as a percentage on dry malt (E_1), and then is:—

$$E_1 = 102.7 - 6.90N - 2.12I \dots \pm 0.8\%.$$

This equation is based on extract figures obtained by coarse grinding and mashing at a constant temperature of 65.55° C. Some adjustment would be necessary for this to agree with the results obtained for extract determined by the "Congress" method.

The size of the protein factor in this equation demonstrates the incompleteness of the original hypothesis of Haase, that protein simply replaces carbohydrate and so exerts a corresponding reduction of extract. While

this is responsible for half the observed effect the other half is due to a "sealing up" of carbohydrate by protein, which becomes more marked in high nitrogen barleys. This applies to the Institute of Brewing Standard Method of Extract Determination; with fine grinding "sealing up" does not occur.

The success of the insoluble carbohydrate factor over a wide range of barleys affords strong support to the "carbohydrate regularity" hypothesis.

A test has also been made of an "insoluble fraction" method which estimates the combined effect of carbohydrates and proteins on extract. It is quick and simple, but gives only an approximate estimate of the extract.

TABLE 2.

REGRESSION EQUATIONS.

No.	Factors.	Equations.	S.E.	V as %
(a) Six Variables. n = 36				
4	—	E = 97.16 = mean	4.33	0
5	N	E = 106.05 — 5.83N	4.10	11
6	NG	E = 92.04 — 8.11N	3.29	42
7	I	E = 119.11 — 2.58I	2.79	60
8	NI	E = 136.61 — 9.12N — 3.00I	1.30	91
9	NIG	E = 133.51 — 9.26N — 2.86I + 0.058G	1.30	91
(b) English Two-row Barleys. n = 104.				
10	—	E = 100.2 = mean	1.65	0
11	I	E = 127.7 — 3.67I	1.32	36
12	N	E = 118.0 — 11.83N	1.17	50
13	NG	E = 109.5 — 11.99N	1.08	58
14	NI	E = 135.6 — 9.91N — 2.74I	0.93	69
15	NIG	E = 131.0 — 10.16N — 2.46I + 0.078G	0.92	70
16	(NG)	Original Plumage-Archer Eqn.	1.12	—
(c) Californian Six-row Barleys. n = 47				
17	—	E = 94.5 = mean	2.07	0
18	N	E = 120.4 — 16.72N	1.28	63
19	NG	E = 109.0 — 13.25N	1.27	64
20	I	E = 137.8 — 4.58I	1.03	76
21	NI	E = 137.4 — 7.86N — 3.25I	0.86	83
22	NIG	E = 153.3 — 10.62N — 3.75I + 0.174G	0.83	85
(d) Two-row plus Six-row barley. n = 151.				
23	—	E = 98.5 = mean	3.18	0
24	N	E = 127.4 — 19.10N	2.54	37
25	NG	E = 143.5 — 19.18N	2.12	56
26	I	E = 123.0 — 3.03I	1.29	84
27	NIG	E = 134.1 — 9.62N — 2.69I + 0.019G	0.91	92
28	NI	E = 134.7 — 9.78N — 2.64I	0.90	92

APPENDIX I.

OUTLINE OF STATISTICAL EVIDENCE.

The methods used in the study are given in Prof. R. A. Fisher's book, "*Statistical Methods for Research Workers*" (Oliver & Boyd), and reference is made to the appropriate section numbers.

The following abbreviations are used :—

E, N, and I as above.

G=weight in grms. of a thousand corns, dry.

S.E.=standard error (see Fisher, § 13).

V=variance accounted for as a percentage of the total variance (see Fisher, § 3).

n=number of barleys and their malts studied.

SECTION II.

Table 2 gives the calculated regression equations for each set (see Fisher, § 25).

SECTION 3.

"Restricted general equation"

$$(29) \dots E = 134.61 - 9.045 (\pm 0.495) N - 2.774 (\pm 0.070) I \dots \pm 0.995 \text{ lb.} \\ (n=187).$$

With factors given as rounded values and with the compensating adjustment of the mean, this gives equation (1).

$$(1) \dots E = 134.7 - 9.0N - 2.8I.$$

SECTION 4.

DERIVATION OF AN EQUATION SHOWING THE EXPECTED EXTRACT FACTORS ON THE HAASE HYPOTHESIS.

It is more convenient to consider the results in terms of "true" extract as a percentage on dry malt (E_2).

The equation expected *a priori* would be :—

$$(3) \dots E_2 = [100 - (\text{insoluble matter in barley})] \times \frac{[324 + 18 \times \frac{1}{2}]}{324}$$

Where $\frac{[324 + 18 \times \frac{1}{2}]}{324}$ is a correction for the

water added in hydrolysis of 75 per cent. of the starch to maltose and 324 and 18 are the equivalent weights of starch and water.

It is known that the loss of carbohydrate by respiration in malting is greater in high nitrogen barleys, but there is a correspondingly greater loss of nitrogen in the rootlets,

so that the equation is not appreciably affected by change of nitrogen content during malting. The total nitrogen of the malt is slightly lower than that of the barley, and the relation does not appear to vary with the malting loss or the nitrogen content. [Malt T.N.=Barley T.N.—0.025]. The difference is partly explained by lack of comparability in the different methods employed for the determination of moisture; that for malt leaves in more water than that for barley. The effect of this on extract is about — 0.5 per cent.

Equation (30) can be expanded by subdividing the insoluble matter :—

$$(31) \dots E_2 = [100 - (\text{insoluble protein} + \text{true insoluble carbohydrate})] \times \frac{337.5}{324}$$

The effect of enzymatic attack on carbohydrates is indirectly included, since the theoretical concept of the "true" insoluble carbohydrates includes all such that are insoluble after malting and mashing.

Taking a conversion factor of 6.0, the protein can be stated in terms of nitrogen.* The proportion of the total nitrogen which becomes soluble must also be allowed for. It has been shown (L. R. Bishop, this *Journ.*, 1931, 345) that with two-row and six-row barleys that 35 per cent. and 27 per cent. respectively of the nitrogen becomes soluble in the wort. Hence 65 per cent. and 73 per cent. remain insoluble, and the expected insoluble protein in terms of total nitrogen is 3.9 (=6.0×0.65) and 4.4 (=6.0×0.73). The mean figure is put at 4.2.

This gives the following anticipated equation :—

$$(32) \dots E_2 = [100 - 4.2N - 1.0 \times (\text{true insoluble carbohydrate})] \times \frac{337.5}{324}$$

giving $E_2 = 104.2 - 4.38N - 1.04 \times (\text{true insoluble carbohydrate})$.

The actual equation obtained (29), when

* As stated in a previous paper, the conventional factor of 6.25 is definitely too high for barley proteins. The factor 5.7 is used in America for wheat proteins, (D. Breeze Jones, Circular 183, U.S. Dept. Agric., 1931) and this is definitely too low, being correct only for the alcohol-soluble protein. In this paper the rounded figure of 6.0 is preferred until the barley proteins have all been isolated in unquestionably pure condition, and the proper factor determined.

converted to give extract as a percentage E_1 , by the factor 0.763, is:—

$$(33) \dots E_1 = 102.7 - 6.90N - 2.12I \dots \pm 0.76.$$

The validity of the comparison is improved further by giving the "true" extract, i.e., the extract corrected for the interfering effect of grains volume. The correcting equation used is:—

$$(34) \dots E_2 = 1.053E_1 - 3.54 \dots$$

(Calculated from results kindly supplied by Mr. F. E. Day.)

Applying this to equation (33), the following equation is obtained:—

$$(35) \dots E_2 = 104.6 - 7.27N - 2.23I$$

Comparison of equations (32) and (35) shows the extent of agreement between theory and actuality. The nitrogen factor (7.27) is significantly higher than the expected, and so is the insoluble carbohydrate factor (2.23). This was shown by "t" tests (Fisher, §29).

"SEALING UP" OF EXTRACT IN THE STANDARD GRIND.

Calculation from the figures for 23 of the 1922 barleys and their malts (from data of H. Lloyd Hind, this *Journ.*, 1924, 971) demonstrated the different relation between nitrogen and extract in the standard and fine grinds.

(36) Standard Grind.

$$E_1 = 81.2 - 6.46N + 0.09G \dots \pm 0.76\%.$$

(37) Fine Grind.

$$E_3 = 80.5 - 4.87N + 0.08G \dots \pm 0.70\%.$$

Where E_3 is the fine grind extract as a percentage on dry malt.

PART PLAYED BY THE DIFFERENT FACTORS.

By means of the analysis of variance (Fisher, §40) it was shown that nitrogen matters only within varieties, and insoluble carbohydrate matters chiefly between, but also to a smaller extent within varieties.

These and other relations discussed in the text are illustrated more simply by means of a table of correlations given below.

TABLE 3.

TABLE OF CORRELATIONS.

		F.	Simple Correlations.						Multiple Correlations.				
			EI.	EN.	EG.	IN.	IG.	NG.	E. NI.	E. NG.	E. IG.	E. NI _G .	
Six Variety Set.													
Total	35	—78	—36	+46	—22	—61	+25	·95	·63	·77	·95
Within varieties	30	—37	—90	+26	+10	—43	—02	·92	·91	·31	·94
Between	„	..	5	—95	+39	+54	—62	—68	+81	·98	·55	·96	·98
Two-row plus Six-row Results.													
Total	150	—92	—61	—44	+37	+56	0	·96	·75	·92	·96
F = number of degrees of freedom in simple correlations.													

F = number of degrees of freedom in simple correlations.

Correlations in heavy type very significant ($p < .01$)

" " ordinary type significant (p between .05 and .01).

" " italic type not significant ($p > .05$)

APPENDIX II.

TABLE 4.

ANALYSES OF BARLEYS AND MALTS STUDIED.

Analyses are on dry weight and are the mean of duplicates except with the extract.

Barley.					Extract of Malt		
Number.	Dry Matter %	Nitrogen %	1000 Corn weight grms.	Insoluble Carbo- hydrate %	Analysis	Pre- diction. (1)	Differ- ence.
<i>The results for Six Varieties are given in Appendix II of a previous paper (this Journ. 1934, p. 74)</i>							
Commercial English two-row.							
1	88.38	1.500	36.9	7.42	100.0	100.5	-0.5
2	88.22	1.517	35.9	7.56	100.5	99.9	+0.6
4	87.90	1.421	37.2	7.28	101.1	101.5	-0.4
5	87.72	1.432	36.5	7.33	101.2	101.3	-0.1
6	87.46	1.381	34.9	7.44	101.6	101.5	+0.1
7	87.36	1.405	35.7	7.52	100.7	101.0	-0.3
8	87.08	1.623	34.8	7.82	97.5	98.2	-0.7
9	88.10	1.341	37.1	7.02	102.8	103.0	-0.2
10	88.28	1.532	31.6	7.72	97.9	99.3	-1.4
13	87.08	1.484	36.6	7.02	101.0	101.7	-0.7
14	87.36	1.482	37.0	7.20	100.1	101.2	-1.1
17	87.26	1.400	33.6	7.78	100.6	100.4	+0.2
22	87.90	1.574	31.9	7.89	97.3	98.4	-1.1
23	88.10	1.686	35.0	7.62	98.1	98.2	-0.1
24	88.97	1.511	31.9	8.03	97.5	98.6	-1.1
28	88.22	1.816	37.3	7.64	97.9	97.0	+0.9
29	87.88	1.554	36.7	7.99	97.9	98.3	-0.4
30	87.72	1.275	36.4	7.54	102.3	102.1	+0.2
31	87.47	1.316	36.4	7.50	102.2	101.9	+0.3
32	87.88	1.332	37.8	7.48	102.8	101.8	+1.0
33	87.92	1.347	35.3	7.40	101.7	101.9	-0.2
38	88.26	1.573	41.2	7.21	100.4	100.4	0
11	87.50	1.422	34.7	7.72	99.2	100.3	-1.1
18	88.06	1.504	38.4	7.60	99.6	99.9	-0.3
19	88.88	1.578	34.7	7.08	100.9	100.7	+0.2
20	88.16	1.636	33.1	7.96	95.9	97.7	-1.8
21	88.10	1.475	36.1	8.24	98.3	98.3	0
26	88.76	1.701	33.6	8.28	95.5	96.2	-0.7
43	88.34	1.586	35.1	7.90	97.7	98.3	-0.6
44	88.48	1.562	38.4	7.02	101.1	101.0	+0.1
45	88.82	1.568	36.7	7.33	101.7	100.1	+1.6
46	88.26	1.566	37.6	7.09	100.6	100.8	-0.2
47	87.94	1.604	33.2	7.69	99.4	98.8	+0.6
48	88.24	1.406	36.2	7.34	101.0	101.0	0
34	87.86	1.442	36.0	7.18	101.6	101.6	0
49	88.50	1.477	30.3	7.22	101.0	101.2	-0.2
50	89.04	1.586	34.9	8.08	97.4	97.8	-0.4
54	88.72	1.479	35.65	7.64	101.5	100.0	+1.5
56	88.86	1.486	37.4	7.41	101.0	100.6	+0.4
59	88.76	1.494	34.55	7.44	100.6	100.4	+0.2
60	88.98	1.488	35.6	7.41	100.4	100.6	-0.2
66	88.34	1.268	37.7	7.62	101.6	102.0	-0.4
67	88.84	1.382	41.4	7.78	102.6	100.5	+2.1
35	88.32	1.343	37.6	7.35	102.8	102.0	+0.8
41	87.90	1.422	36.2	7.34	101.8	101.4	+0.4
42	87.70	1.410	37.0	7.16	101.7	102.0	-0.3
55	87.84	1.414	37.4	7.06	101.7	102.2	-0.5
57	87.36	1.452	34.7	7.37	101.8	101.0	+0.8
58	87.72	1.421	35.8	7.32	102.0	101.4	+0.6
89	87.24	1.450	35.4	7.43	100.8	100.9	-0.1
90	87.64	1.411	33.0	7.66	99.7	100.6	-0.9
91	87.26	1.476	37.4	7.31	101.4	101.0	+0.4
120	87.00	1.512	33.8	7.39	101.2	100.4	+0.8
71	88.04	1.627	34.85	7.82	96.7	98.2	-1.5
103	87.86	1.468	35.7	7.52	101.4	100.4	+1.0

Barley.					Extract of Malt.		
Number.	Dry Matter %	Nitrogen %	1000 Corn weigh grms.	Insoluble Carbo-hydrate %	Analysis	Prediction. (l)	Difference.
104	87.90	1.458	36.0	7.40	100.4	100.9	-0.5
105	88.30	1.458	35.3	7.66	101.2	100.2	+1.0
121	87.72	1.507	34.6	7.38	101.7	100.5	+1.2
129	87.06	1.438	34.4	7.49	101.1	100.8	+0.3
134	87.10	1.426	37.4	7.34	102.3	101.3	+1.0
135	87.82	1.423	38.2	7.28	101.7	101.5	+0.2
141	87.80	1.338	36.8	7.46	101.3	101.7	-0.4
153	87.84	1.413	35.0	7.65	100.9	100.6	+0.3
65	86.98	1.627	39.2	7.45	100.0	99.3	+0.7
87	87.2	1.402	35.0	7.56	102.2	100.9	+1.3
97	86.66	1.488	36.5	7.54	99.8	100.2	-0.4
98	88.14	1.605	38.2	7.41	99.1	99.5	-0.4
99	87.58	1.617	37.4	7.53	99.2	99.1	+0.1
122	87.62	1.634	41.1	7.12	98.3	100.1	-1.8
131	87.96	1.496	34.8	7.50	100.1	100.2	-0.1
133	87.32	1.354	38.9	7.32	102.2	102.0	+0.2
137	86.94	1.454	36.1	7.50	99.6	100.6	-1.0
142	87.18	1.452	34.3	7.60	100.8	100.4	+0.4
158	87.36	1.623	37.5	7.32	99.7	99.7	0
172	87.44	1.540	41.1	7.31	97.9	100.4	-2.5
51	87.16	1.579	35.1	7.92	98.6	98.4	+0.2
52	87.28	1.624	34.5	7.92	97.4	97.9	-0.5
61	86.96	1.434	36.5	7.32	101.6	101.3	+0.3
62	86.60	1.535	36.4	7.44	101.2	100.1	+1.1
82	88.48	1.526	38.0	7.36	99.0	100.4	-1.4
100	87.72	1.592	36.0	7.44	100.0	99.6	+0.4
111	87.82	1.547	34.7	7.39	102.1	100.4	+1.7
112	87.80	1.407	35.5	7.21	101.5	101.8	-0.3
130	86.70	1.370	34.4	7.44	100.8	101.6	-0.8
151	87.20	1.478	37.8	7.16	101.2	101.3	-0.1
152	87.58	1.494	38.3	6.78	101.4	102.3	-0.9
155	87.44	1.548	39.1	7.22	101.0	100.6	+0.4
159	87.44	1.647	37.6	8.02	99.3	97.5	+1.8
85	87.04	1.448	35.1	7.49	100.2	100.7	-0.5
86	86.84	1.436	36.4	7.32	100.7	101.3	-0.6
106	86.96	1.558	35.5	7.61	99.3	99.4	-0.1
113	87.00	1.484	39.3	7.62	101.6	100.0	+1.6
116	87.18	1.617	38.7	7.47	100.2	99.3	+0.9
118	87.26	1.592	38.6	7.66	99.2	99.0	+0.2
119	87.38	1.602	37.5	7.50	99.5	99.3	+0.2
123	87.52	1.629	38.2	7.54	98.5	99.0	-0.5
136	87.44	1.484	35.2	7.44	100.0	100.5	-0.5
145	87.32	1.665	40.9	7.14	100.4	99.7	+0.7
156	87.12	1.500	37.1	7.54	100.2	100.1	+0.1
157	87.12	1.476	36.3	7.37	98.9	100.8	-1.9
160	87.50	1.492	38.4	7.52	100.1	100.2	-0.1
173	87.10	1.638	35.0	7.74	95.0	98.3	-3.3
179	86.86	1.447	37.1	7.28	100.4	101.3	-0.9
181	87.20	1.536	34.5	7.77	100.9	99.2	+1.7

APPENDIX III.

TABLE 4.

ANALYSES OF BARLEYS AND MALTS STUDIED.

Analyses are on dry weight and are the mean of duplicates except with the extract.

Barley.								Extract of Malt.		
Letter.	Number.	Dry Matter %	Nitrogen %	1000 Corn weight grms.	Insoluble Carbo-hydrate %	Analysis	Prediction. (1)	Difference.		
Commercial Californian Six-row.										
PR	4/3	87.56	1.529	40.1	9.40	95.7	94.7	+1.0	
		5/3	88.08	1.563	40.1	9.34	95.6	94.6	+1.0	
		10/3	87.66	1.520	39.4	9.21	95.2	95.3	-0.1	
		11/3	87.66	1.547	39.5	9.53	95.2	94.1	+1.1	
		12/3	87.20	1.540	40.0	9.68	95.6	93.8	+1.8	
IN	3D	87.66	1.420	43.0	9.09	96.6	96.5	+0.1	
		4D	87.32	1.394	44.25	9.22	96.0	96.3	-0.3	
		5D	87.66	1.393	44.2	9.18	96.7	96.5	+0.2	
		6D	87.90	1.450	43.7	8.98	96.4	96.5	-0.1	
		7D	88.12	1.421	44.3	8.97	96.8	96.8	0	
Buc.	3AB	87.48	1.535	45.0	9.39	93.1	94.6	-1.5	
		4AB	87.66	1.520	43.7	9.61	93.9	94.1	-0.2	
		18/3	87.00	1.496	43.5	9.52	92.9	94.6	-1.7	
		19/C, D, E.	87.55	1.488	44.5	9.54	93.1	94.6	-1.5	
		35/C, D, E.	88.11	1.529	44.8	9.75	93.2	93.7	-0.5	
PN	8D	87.40	1.691	37.6	9.84	91.9	92.0	-0.1	
		9D	87.60	1.655	39.1	9.74	92.6	92.6	0	
		10D	87.86	1.635	39.6	9.82	91.6	92.5	-0.9	
		11D	87.74	1.654	38.2	9.78	91.8	92.4	-0.6	
		12D	88.26	1.695	40.1	9.68	92.2	92.3	-0.1	
		13D	87.82	1.659	38.6	9.73	91.7	92.6	-0.9	
		21D	88.20	1.654	39.6	9.80	92.4	92.4	0	
		22D	88.20	1.649	40.5	9.67	93.4	92.8	+0.6	
		23D	88.40	1.650	38.6	9.58	92.9	93.1	-0.2	
		24D	89.33	1.621	39.7	9.57	93.1	93.4	-0.3	
Cor.	13/3	87.02	1.618	40.4	9.67	93.7	93.1	+0.6	
		14/3	87.02	1.569	41.4	9.54	94.6	93.9	+0.7	
		15/3	87.68	1.591	40.7	9.46	94.6	93.9	+0.7	
		16/3	87.40	1.665	40.0	9.62	93.5	92.8	+0.7	
IN/1	25D	89.12	1.688	36.1	9.98	92.1	91.6	+0.5	
		26D	89.40	1.672	35.9	9.92	92.8	91.9	+0.9	
Buc/Cor	17/3	87.30	1.570	42.6	9.52	93.5	94.0	-0.5	
AJ	26/3	88.48	1.397	46.6	8.96	97.6	97.1	+0.5	
		29/3	88.95	1.421	45.0	8.99	97.4	96.7	+0.7	
		30/3	88.22	1.397	46.1	8.78	97.3	97.5	-0.2	
		32/3	88.20	1.396	46.3	8.97	97.6	97.1	+0.5	
		35/3	88.70	1.444	44.5	8.98	97.0	96.6	+0.4	
		38/3	88.16	1.419	45.0	9.22	97.6	96.1	+1.5	
		36/3	89.00	1.430	44.2	9.12	96.8	96.3	+0.5	
TC	30/1	88.70	1.650	38.6	9.80	91.0	92.5	-1.5	
		31/1	88.21	1.631	37.2	10.08	92.8	91.8	+1.0	
		32/1	88.29	1.626	38.6	10.12	93.0	91.8	+1.2	
		33/1	88.22	1.630	38.6	10.18	93.1	91.6	+1.5	
AM	14D	87.94	1.610	43.8	8.68	97.1	96.0	+1.1	
		15D	87.14	1.559	43.7	8.76	96.6	96.2	+0.4	
		19D	88.60	1.585	44.0	8.74	97.2	96.0	+1.2	
		20D	88.30	1.560	43.6	8.77	97.3	96.2	+1.1	

Barley.						Extract of Malt.		
Letter.	Number.	Dry Matter %	Nitrogen %	1000 Corn weight grms.	Insoluble Carbo-hydrate %	Analysis	Prediction. (1)	Difference.
Other Varieties.								
July		87.56	1.240	23.0	8.11	101.6	100.9	+0.7
O.A.C. 21	'28	86.52	2.09	32.1	9.05	92.1	90.6	+1.5
Trebti	'28	86.72	1.77	45.2	8.40	94.3	95.3	-1.0
	'30	85.08	1.946	42.6	8.42	87.9	93.6	-5.7
	'32	87.54	1.436	46.6	8.94	95.8	96.8	-1.0
Commercial Californian	9 & 10, '31	87.72	1.454	41.7	9.13	96.5	96.0	+0.5
Hero	'25	87.14	1.931	45.4	10.14	86.2	80.0	-2.8
Vaughn	7, '31	87.94	2.200	36.1	9.41	85.9	87.8	-1.9
Tennessee Winter ..	'26	87.66	2.262	30.8	10.25	87.2	85.7	+1.5
	2, '31	87.76	1.181	37.4	9.68	97.3	97.0	+0.3
	11, '31	88.00	1.510	38.9	9.46	94.0	94.6	-0.6
Mariout	'26	87.96	2.259	46.5	9.68	87.5	87.3	+0.2
	24, '31	88.22	1.377	44.4	9.36	94.8	96.1	-1.3
Coast	'26	87.74	2.139	32.7	11.25	86.8	84.0	+2.8
Smooth Awn	'26	87.42	1.812	42.8	9.42	89.4	92.0	-2.6
B 244	199, '27	88.48	1.513	32.8	8.04	94.6	98.6	-4.0
	200c, '28	88.30	1.477	32.5	7.41	99.2	100.7	-1.5
	131, '29	88.90	1.788	34.7	7.70	94.0	97.1	-3.1
	110c, '30	88.18	1.370	31.6	7.18	98.7	102.3	-3.6
	111c, '30	87.90	1.354	30.4	7.47	98.1	101.6	-3.5
	115c, '30	89.22	1.342	30.2	7.64	97.4	101.2	-3.8
	116c, '30	88.82	1.377	30.4	7.64	97.5	100.9	-3.4

Rothamsted Experimental Station,
Harpenden, Herts.
22nd December, 1933.

INSTITUTE OF BREWING RESEARCH SCHEME.

NOTE ON THE PHOSPHORIC ACID OF BARLEY GRAIN

By E. M. CROWTHER, D.Sc., F.I.C.

DETERMINATIONS of phosphoric acid in the dry matter of barley grain were made on 127 samples taken from 4 series of field experiments conducted under the Institute of Brewing Research Scheme. (See Barley Research Reports, this *Journ.*, 1923, 624, 1924, 624; 818, 969; 1925, 104, 548, 601; 1927, 104; 1928, 307, 321, 436.) The samples were selected so as to investigate the influence of soil, season, varieties, and manuring. All of them had been previously valued and analysed by the usual methods of barley and malt analysis, so that it was possible to examine the association of variations in phosphoric acid content with those of other important characteristics. The finely ground barley grain was moistened with calcium acetate solution and carefully ashed. The residue was evaporated to dryness with nitric acid and taken up again in nitric acid. The phosphoric acid was determined by the Lorenz method, the detailed procedure for precipitation and drying of the phosphomolybdate being that elaborated by Neubauer for seedling analysis, (*Cf.* H. Neubauer *Z. Pflanz. Dung., A.*, 1923, 329. *Arbeiten der Zuckerfabrik Kleinwanzleben* III, 1927) The results of the four series are discussed briefly in turn. A more general discussion of the relation of soil conditions to nutrient uptake and barley yield and quality is given by L. R. Bishop in this issue.

Series 1.—General manurial trials at Rothamsted, Wellingore, Woburn, Eyton, and Orwell Park centres, 1922 to 1925, and Porlock, 1923-24 (98 samples). There are unfortunately several gaps in the series, where the whole of the stored sample had been used up in earlier analyses, and a rigid statistical analysis is not, therefore, attempted. The average manurial effects are

shown at the bottom of Table I., and for comparison the average nitrogen contents for the same plots are given. It is at once obvious that the fertilisers have had little effect on either, and that the effect on P_2O_5 per cent. is even less than that on N per cent. There is some evidence that nitrogenous manures slightly reduce the P_2O_5 per cent. The P_2O_5 content of the three sets of plots receiving nitrogen (average 0.950 per cent.) is slightly below that of the two sets without nitrogen (average 0.969 per cent.). All fertiliser mixtures reduced the nitrogen content of the grain and the combination of potash and phosphate gave the lowest N per cent. but the highest P_2O_5 per cent.

Wide variations in soil and season produced no very great differences in P_2O_5 per cent., the extreme values for the individual plots being 1.18 per cent. and 0.74 per cent. In Table II. the values for the 5 plots at each centre in each year have been averaged to obtain more representative values after eliminating manurial effects. The variations from year to year are about the same as those from centre to centre. No general relationship was found between P_2O_5 content and any one of the following.—Yield, barley valuation, malt valuation, nitrogen content, 1000 corn weight, diastatic power, cold water extract and extract calculated on barley. In 1922, 1923 and 1924 high P_2O_5 per cent. and high cold water extract were associated, but there were exceptions in 1925. It should be noted, however, that none of the analytical data available for these barleys and malts related to those processes in which the phosphorus might be expected to exert a direct effect as, e.g., on the reaction and buffering during brewing and on the nutrition or stimulation of the yeast.

TABLE I.—*General Manurial Trials, 1922-1925—Individual plots (98 samples).*(Per cent. P_2O_5 in dry matter.)

Plots Manure	1 Unmanured.	2 Nitrogen Phosphate Potash.	3 Nitrogen Phosphate	4 Nitrogen Potash.	5 Phosphate Potash.
Rothamsted, 1922	0·947	—	0·903	0·894	0·912
1923	—	0·988	1·006	0·966	—
1924	1·042	1·007	1·004	0·987	1·031
1925	0·967	0·927	0·933	0·924	0·982
Wellingore, 1922	1·047	1·047	—	1·042	—
1923	—	0·994	0·973	0·975	0·984
1924	0·982	0·961	1·008	0·960	0·976
1925	0·939	0·894	0·932	0·876	0·916
Woburn, 1922	0·958	0·918	0·910	0·904	0·900
1923	1·049	0·993	0·995	1·002	1·001
1924	0·966	0·933	0·922	0·952	0·972
1925	0·998	1·007	—	—	1·042
Eyton, 1922	0·967	0·946	0·955	0·991	0·933
1923	0·743	0·857	0·869	0·837	0·898
1924	0·907	0·923	0·928	0·924	0·973
1925	0·937	0·861	0·769	—	—
Orwell Park, 1922	1·021	—	0·984	0·981	1·039
1923	1·161	1·180	1·137	1·148	1·146
1924	1·030	1·081	1·008	0·980	1·023
1925	0·865	0·783	0·855	0·766	0·802
Porlock, 1924	—	1·003	1·000	0·976	0·999
1925	0·881	0·867	0·867	0·865	0·894
Average of all centres and years	Per cent. P_2O_5 0·969 Per cent. N 1·646	0·954 1·620	0·948 1·627	0·948 1·606	0·970 1·586

TABLE II. — *General Manurial Trials, 1922-1925.**Averages for all manurial plots for each centre and year (per cent. P_2O_5 in dry matter.)*

Year	1922.	1923.	1924	1925.	Average for 4 years at individual centres.
Rothamsted	0·914	0·987	1·014	0·947	0·966
Wellingore	1·045	0·982	0·978	0·911	0·979
Woburn	0·918	1·008	0·949	1·016	0·973
Eyton	0·958	0·841	0·931	0·856	0·897
Orwell Park	1·006	1·154	1·004	0·814	0·965
Averages for 5 centres in individual years	0·968	0·994	0·975	0·909	General average 0·962
Porlock	—	—	0·995	0·875	Average of all samples 0·967

At the three centres in Series II (Table III.) addition of nitrogen whether as ammonium sulphate or chloride slightly reduces the P_2O_5 per cent. Again in Series III the P_2O_5 content decreased regularly with increasing nitrogen in the manure, up to $1\frac{1}{2}$ cwt. sulphate of ammonia per acre. Land made initially richer in nitrogen by eating off the preceding crop by sheep gave barley of a much higher N per cent., but of

substantially the same P_2O_5 per cent. as that from which the preceding crop was removed. Although in all cases the reduction in P_2O_5 per cent. by the addition of a nitrogenous manure is small, the effect is shown without exception in Series II and III, and in the general average of Series I.

The results given in Table V. refer to barleys grown in 1927 at the Norfolk Agricultural Station in connection with the

TABLE III.

SERIES II. *Influence of nitrogenous fertilisers on plots for experimental brewings, 1927. (8 samples).*

	Per cent. N. in dry matter.			Per cent. P_2O_5 in dry matter.		
	No N.	Sulph. Amm.	Muriate Amm.	No N.	Sulph. Amm.	Muriate Amm.
Centre	1.461	1.576	1.512	1.034	1.031	1.026
Bruce, Longniddry	1.477	1.493	1.520	0.985	0.911	0.936
Andrew, Fitzhead	1.412	1.336	—	0.996	0.950	—
Norfolk Agric. Station	1.450	1.468	—	1.005	0.964	—
Average	1.450	1.468	—	1.005	0.964	—

National Institute of Agricultural Botany variety trials.

The analytical results given in Table V. refer to barleys grown in 1927 at the Norfolk Agricultural Station in connection with the National Institute of Agricultural Botany variety trials.

TABLE IV.

SERIES III.—*Influence of increasing amounts of ammonium sulphate at Norfolk Centre, 1927. (7 samples—%N and % P_2O_5 in dry matter).*

Sulphate of ammon- ia per acre.	Barley grown not after sheep		Barley grown after sheep	
	N	P_2O_5	N	P_2O_5
0	1.375	0.908	1.530	0.901
$\frac{1}{2}$ cwt.	1.285	0.875	1.447	0.884
1 cwt.	1.266	0.854	1.462	0.869
$1\frac{1}{2}$ cwt.	1.296	0.854	—	—

There is considerable variation in P_2O_5 per cent. between the varieties, the extreme values being 0.899 and 0.966 for Spring barleys and 0.954 and 1.050 for Winter barleys. The Winter barleys are considerably richer in P_2O_5 than the Spring barleys, whether comparisons be made for the whole series or restricted to the three varieties which were grown under both conditions. In the Spring barleys there is no connection between N per cent and P_2O_5 per cent. In the Winter barleys high

TABLE V.

SERIES IV. *N.I.A.B. Variety Trials on Spring and Winter Barley at Sprowston, 1927.*

No.	Variety	N% in dry barley	P_2O_5 % in dry barley	Valua- tion
<i>Spring Barleys.</i>				
163	Webb's Sunrise	1.293	0.966	63
162	Beaven's Archer	1.372	0.961	63
168	824	1.436	0.960	68
				(damaged)
167	New Cross	1.313	0.939	63
168A	825	1.417	0.938	63
165	Archer Goldthorpe	1.378	0.937	63
164	Spratt Archer	1.332	0.931	70
166	Beaven's 25	1.337	0.912	68
166c	Plumage-Archer	—	—	—
	(Control to 824)	1.297	0.889	70
<i>Winter Barleys.</i>				
195	Webb's Sunrise	1.380	1.050	48
193	Selected Archer	1.323	1.037	48
194	Spratt Archer	1.321	1.020	48
142c	F 112	1.307	0.978	35
142	Plumage Archer	1.190	0.954	70

values of both tend to be associated, but for 5 samples this may be fortuitous. Both as Spring and as Autumn barley Plumage Archer had the highest valuation and the lowest P_2O_5 per cent. and Webb's Sunrise the highest P_2O_5 per cent. and a low valuation.

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*The Relationship between Viscosity, Elasticity and Plastic Strength
of Soft Materials as Illustrated by some Mechanical Properties
of Flour Doughs, I.*

By ROBERT KENWORTHY SCHOFIELD and GEORGE WILLIAM SCOTT BLAIR.

(Communicated by Sir John Russell, F.R.S.—Received July 8, 1932.)

[PLATE 15.]

I. Flour dough belongs to a group of materials in which a high degree of plasticity is combined with considerable elasticity. Owing to their great industrial importance, a number of technological investigations have been carried out on these materials (of which unvulcanised rubber is another important example); but the problem of bringing the description of their behaviour within the scope of a general theory of viscosity and elasticity has hardly been tackled.

The time during which a stress is applied is as important as the magnitude of the stress in determining how much of the deformation is elastic (recoverable) and how much plastic (non-recoverable). This fact suggests that a formulation based on Maxwell's "time of relaxation" should be of value in this connection. The formulation as Maxwell gave it applies to a true fluid, for which case the relaxation is exponential and for which the rate of dissipation of internal

stress is proportional to the stress, the constant of proportionality being the reciprocal of the relaxation time. Thus

$$-\frac{ds}{dt} = \frac{1}{t_r} S,$$

or

$$\frac{1}{t_r} = -\frac{1}{S} \frac{dS}{dt} = -\frac{d(\log_e S)}{dt},$$

where S is the shearing stress, and t_r the relaxation time.

An obvious method of extending this conception to plastic materials is to recognise the relaxation time as a quantity which is not a constant but which varies according to the stress, and to consider its reciprocal as determined by $-d(\log_e S)/dt$. Thus the reaction of the material to an external stress will be more purely elastic in proportion as the time of relaxation exceeds the time of application.

In handling a flour dough, strains up to 30 per cent. given momentarily recover almost completely, so that, for the corresponding stresses, the time of relaxation must be large enough to be measured without the aid of elaborate apparatus. The reason for this is brought out by a further consideration of Maxwell's theory. In steady flow the velocity gradient (or rate of change of shearing strain), G , is related to the rate of dissipation of internal stress by the rigidity modulus, n , of the material. Thus

$$-\frac{dS}{dt} = nG.$$

So that the viscosity, η , which is defined as the ratio of S to G is given by

$$\eta = nt_r. \quad (1)$$

Hence

$$t_r = \eta/n.$$

In the case of plastic materials, η , if defined as the ratio of S to G , is not a constant,* but varies with S ; n , on the other hand, appears to be a constant of

* There is no universally recognised definition of viscosity in systems other than true fluids. In certain cases, although S/G varies, dS/dG is constant over a considerable range of stress. In such cases the behaviour of the system is conveniently described in terms of dS/dG which has been termed the "pseudo-viscosity"† or "stiffness," its reciprocal being Bingham's "mobility."‡ It seems best to reserve the term viscosity for the simple ratio S/G , and recognise that, in general, this varies with S .

† Scott Blair and Crowther, 'J. Phys. Chem.,' vol. 33, p. 321 (1929).

‡ Bingham, "Fluidity and Plasticity" (1922).

the material. Under low stresses the value of η for flour dough is considerable, while the rigidity modulus is extremely small by comparison with that of ordinary solids. It is the combination of these extreme properties which gives this material a special interest, and makes its study valuable for the purpose of advancing our general understanding of these systems.

2. Experiments which have enabled a direct determination to be made of t_r are dealt with in Section 3. It is convenient, however, before describing these to outline the results of some preliminary experiments which bring out the importance of the time of application in determining the type of reaction to an external stress. The first experiments were carried out with the pachimeter, an instrument for measuring plastic strength under rolling which has already been described in detail in its application to the study of soils.* A test piece in the form of a small cylinder of known radius and length is made to roll between two horizontal plates by reciprocating the lower one, and the instrument is designed to measure the stress which must be exerted by the upper plate in order to produce in the rolling cylinder a permanent elongation.

It was thought that the plastic strength of a dough thus determined might have an important bearing on the baking quality of the flour. It was found that the instrument is capable of distinguishing between flours, but the results did not run entirely parallel with the bakers' opinion. It is now clear that at least one reason for this is that, while the stresses set up by the gas generated in a yeasted dough operate over a time to be measured in hours, the reciprocating action in the pachimeter impresses a stress on any given diameter of the rolling dough cylinder for only a fraction of a second. The fact that a dough cylinder does not show a measurable permanent elongation until a stress greater than a certain critical stress has been applied between the plates must be interpreted as showing that below this critical stress the time of relaxation is too long for any measurable plastic deformation to occur in the time allowed by the instrument. The remarkable reproducibility of the figures given by this instrument is evidently due, in part, to the fixing of the time of application of the stress by the speed of reciprocation; but it must also, in part, be attributed to the rolling action, through which every diameter comes under stress in turn thereby averaging out the effects of irregularities in the specimen. It is evident, however, that for such a material the terms *plastic strength*, and *yield value*, if used to describe the figures obtained, must be construed as

* Schofield and Scott Blair, 'J. Agric. Sci.', vol. 132, p. 135 (1932); 'J. Soc. Chem. Ind.', vol. 51, p. 205 (1932); 'Trans. Ceram. Soc.', vol. 31, p. 79 (1932).

relative rather than absolute terms. A second series of measurements was made on a newly designed instrument which we have called a rack owing to its superficial resemblance to an ancient instrument of torture, fig. 8, Plate 15. Long cylindrical pieces of dough (made by forcing the material through a short piece of metal tubing attached to the body of a grease gun) were stretched out and held stretched for a measured time, at the end of which they were cut loose and their elastic contraction measured.*

Fig. 1 shows the result of a series of experiments in which cylinders of a dough† of a good bakers' mixture were stretched to different extents and cut loose after 1 minute. It will be seen that the elastic recovery, expressed as

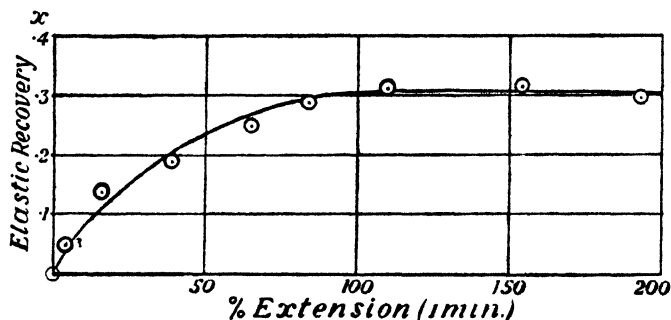


FIG. 1.

the ratio of the contraction to the final length, increased as the initial extension was increased to 100 per cent., but that no further increase was obtained up to 200 per cent. A curve resembling the earlier portion would be obtained on plotting the same quantities for a copper wire as may be seen from the data recently published by Taylor and Quinney.‡ It is not suggested that the correspondence is complete, but a due recognition of the widely different relaxation times involved in the two cases does much to bridge the gap. In a further series of measurements cylinders made from portions broken from a large dough at intervals during a period of several hours were stretched to

* The satisfactory agreement obtained between duplicate dough cylinders made up by this method demonstrates that any irregular strains set up in the dough in the grease gun are not great enough to upset the behaviour of the cylinder when under stress.

† In comparing doughs made from different flours it was not convenient to use in every case the same proportion of flour to water. It was found possible to reproduce dough samples most satisfactorily by making them up to that moisture content at which they will just not stick to a glass plate when pressed firmly on to its surface. All doughs were made up with 25 per cent. salt solution.

‡ 'Phil. Trans.,' A, vol. 230, p. 323 (1931).

just over 100 per cent. and their elastic recovery after 1 minute was measured. No appreciable differences were found. These results are in striking contrast to those obtained from portions of the same dough and investigated in the pachimeter. As will be seen from fig. 2 the pachimeter-values (W) show

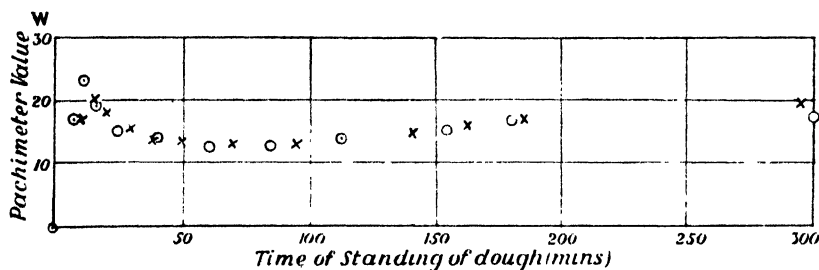


FIG. 2.—○ × duplicate doughs.

marked fluctuations with time. In order to ascertain whether the results from the two instruments differ because of a relative shortness of time under stress in the pachimeter, a simple experiment was made. The apparatus constructed consisted essentially of a ballistic pendulum which, being released from an angle of 25° , was allowed, when at the lowest point of its swing, to strike and rebound from the circular face of a cylinder of dough. The cylinder had a radius of 3 mm. and length 15 mm. and was held in an L-shaped support so that the end away from the pendulum remained rigid and the cylinder was given support from below for about three-quarters of its length. The pendulum bob consisted of a clay marble weighing 2.3 gm. supported by two threads

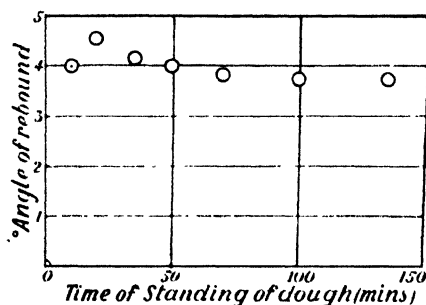


FIG. 3.

45 cm. long separated by 15 cm. at their upper end. The results, shown in fig. 3 (each point represents a mean of three readings) confirm the expectation that the larger values of W , since they indicate a smaller dissipation of rapidly applied stresses, correspond to bigger angles of rebound.

Although this is not the place to discuss how far the variations in W reflect the colloidal and other changes which take place between the time when a baker first mixes his dough and that when it is "ripe" for baking, it is interesting to note that there is a correspondence between them and the variation of consistency of flour pastes as recorded by Jago for doughs* and by Denham, Scott Blair and Watts and others† for flour pastes. Since these consistency measurements were made by observation of fairly rapid flow through capillary tubes, it is satisfactory to note that agreement is shown with the pachimeter in which shearing is rapid rather than with the rack where the relaxation of stress is slow.

3. The rack may also be used to determine the time of relaxation for a certain range of stresses. For if, as seems reasonable, we may assume a constant proportionality to exist between the elastic recovery, x , and the stress still undissipated at the time of cutting loose, the reciprocal of the time of relaxation is as well given by $-d(\log_e x)/dt$ as by $-d(\log_e s)/dt$.‡ The former quantity can be evaluated by obtaining from a series of experiments, in which the initial deformation is the same, the variation of x with the time during which the cylinder is held deformed. The result of such a series is shown in fig. 4, the circles giving the values of x and the crosses of $\log_e x$. Fig. 5 gives

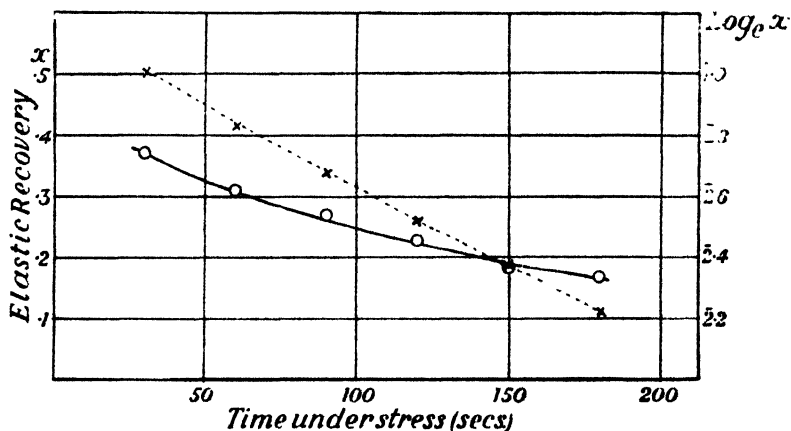


FIG. 4. $\odot = x$, $\times = \log_e x$.

* Jago, "Chemistry of Wheat, Flour, and Bread, and Technology of Bread Making" (1886 and later editions).

† Denham, Scott Blair and Watts, 'Cereal Chem.', vol. 4, p. 206 (1927); Sharp and Gortner, 'Tech. Bull. Minn. Agr. Exp. Sta., No. 19,' (1923); St. John and Bailey, 'Cereal Chem.', vol. 4, p. 140 (1929).

‡ Where s is the tensile stress per unit area (equals $3S$, see below), the stress plotted in figs. 5, 6 and 7 is the tensile stress, s .

the variation of the time of relaxation with the stress. In order to deduce the undissipated stress plotted as abscissa it was necessary to obtain the appropriate value for Young's modulus. For this purpose observations were made on the compression caused by placing a small weight on top of a squat cylinder of dough 1 cm. high and 0.55 cm. mean diameter. A fourfold magnification was obtained in measuring the deformation by an arrangement resembling the backsight of a rifle. This method was used because it was simple, and enabled the readings to be taken in quick succession, so that the cylinder was not loaded long enough for any appreciable plastic flow to take place, fig. 9,

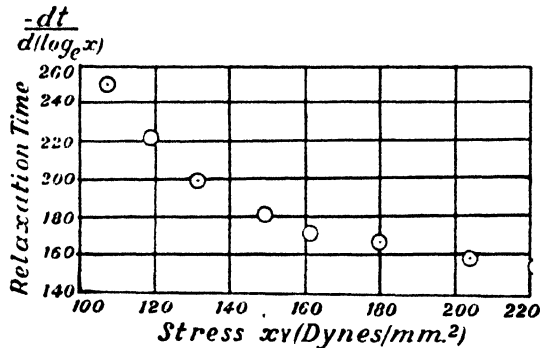


FIG. 5.

Plate 15. A mean value of about 4×10^4 dynes per square centimetre was obtained, and no variations could be detected during the ageing of a dough. This figure is admittedly only approximate, as, apart from the smallness of the deformation to be measured, it was difficult to form the dough into a true cylinder and obtain a satisfactory value for its cross-section. On the other hand, it is certainly not seriously in error; but since higher values were obtained by another method, to be described later, a somewhat higher value, namely, 6×10^4 has been adopted.

In order to obtain a check on the general correctness of fig. 5 and also to extend the stress range of the determination of the time of relaxation, a modification of the rack was constructed in which the weight of the dough cylinder was supported on a pool of mercury contained in a long shallow wooden trough. One end of the dough was fixed by pressing it round a screw let into one end of the trough while the other was attached to a thin strand of rubber by the extension of which the stress on the dough could be observed. The other end of the rubber strand was secured to a thread which could be wound up on a small winch. Direct observations on the decay of the stress were made by

first rapidly extending the dough by winding the thread on to the winch until after an extension of about 150 per cent. an ink mark on the dough came into the field of view of a low-power microscope. The thread was then gradually released at rate carefully regulated so as to keep the ink mark on the cross-wire of the microscope. From a separate calibration the stress corresponding to each notch was known, and this, divided by the mean cross-section, gave the ordinate of fig. 6, the abscissa being the recorded times. In fig. 7 is given

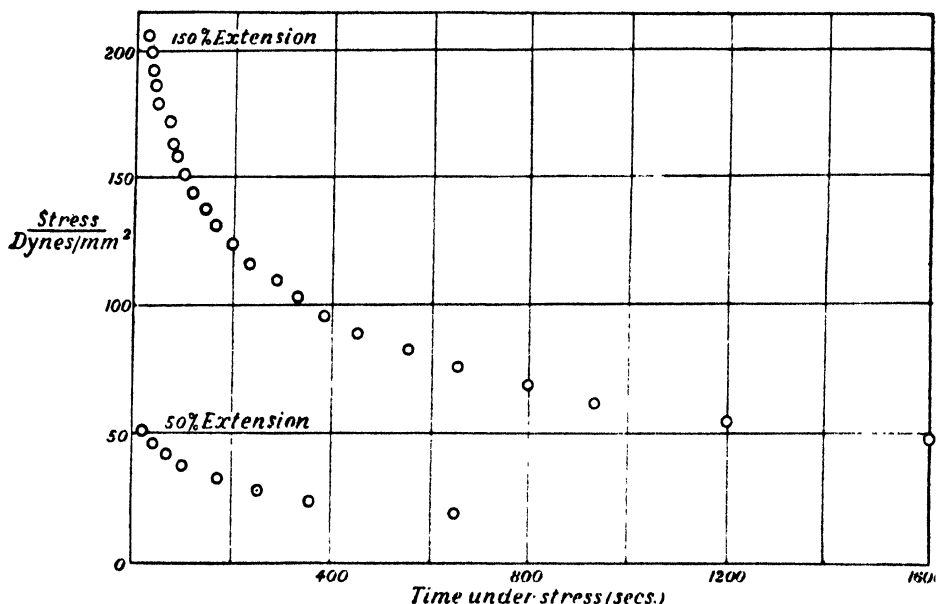


FIG. 6.

the curve for the relaxation time derived from it. It shares with fig. 5 the uncertainty attached to the evaluation of a cross-section, but is in other respects more reliable and extends over a much wider range.

In figs. 6 and 7 are also shown curves relating to the decay of stress for an initial deformation of only 50 per cent. The lack of agreement between the two curves in fig. 7 shows that the time of relaxation depends on the deformation the specimen has suffered as well as on the stress. The dependence of time of relaxation (and hence of viscosity) on the total deformation was suspected from the results of some rougher comparisons of a similar nature made with the original rack. It has been confirmed in a new series of experiments in which observations have been made of the plastic extension of dough cylinders under their own weight, an account of which will be published shortly.

In these experiments it has been found that although the cylinders thin considerably in extending there is no corresponding increase in the rate of extension. This phenomenon may be compared on the one hand with the hardening of metals under working and on the other with an analogous effect observed by Trouton in the case of pitch.* These results point out a weakness† in the usual methods of measuring viscosity by observations on steady flow. Unless special care is taken the only value obtained for the viscosity will be the limiting value for large total deformations.

In a complete study of the plastic behaviour of such a material the viscosity-stress relationship should be found for a series of deformations. The measure-

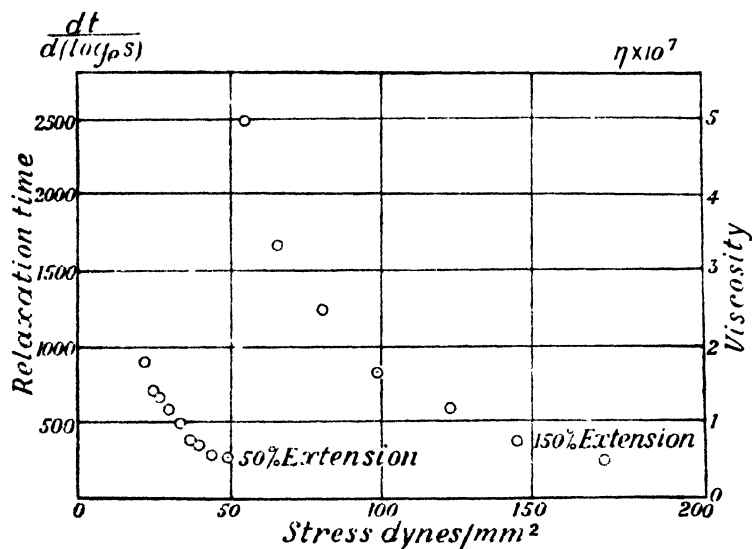


FIG. 7.

ment of flow at constant deformation may seem at first sight to be impossible, but this is actually what was done in the experiments just described. While the winch remained on a given notch the dough was flowing slowly under a substantially constant stress. Before it had gone far, however, the stress was reduced and an elastic recovery occurred equal and opposite to the deformation

* 'Proc. Roy. Soc.,' A, vol. 77, p. 426 (1906).

† The determination of viscosity by the usual methods is also liable to disturbance from slip or anomalous flow at the solid surfaces of the viscometer (Schofield, R. K., and Scott Blair, G. W., 'J. Phys. Chem.,' vol. 34, p. 248, 1505 (1930); 'J. Phys. Chem.,' vol. 35, p. 1212 (1931); 'Phil. Mag.,' vol. 72, p. 890 (1931)). In the method here described no such complication can arise.

caused by the flow. This deformation can therefore be obtained by dividing the stress change by Young's modulus.

According to well-known principles a material such as this for which Poisson's ratio may be taken as $\frac{1}{2}$, when elongated may be considered as subject to two shearing strains each equal in magnitude to the fractional elongation. The corresponding shearing stresses are each one-third of the normal tensile stresses applied in causing the elongation, so that by plotting the rate of shear $-\frac{1}{Y} \frac{ds}{dt}$ against the shearing stress, $\frac{1}{3}s$, a flow-curve is obtained. The viscosity corresponding to any given stress s is therefore given by

$$\eta = -\frac{1}{3}s \left/ \frac{1}{Y} \frac{ds}{dt} \right.,$$

but

$$t_r = -s \left/ \frac{ds}{dt} \right..$$

Therefore

$$\eta = \frac{1}{3}Y t_r.$$

This result might have been deduced directly from equation (1) (p. 708), since when Poisson's ratio is $\frac{1}{2}$, $Y = 3n$; but its independent deduction serves a useful purpose if it helps to make clear how viscosity can be measured, in the case of a markedly elastic material, at constant deformation. The change which goes on in a dough held at constant deformation involves an increase of the plastic part of the deformation at the expense of the elastic part; and the rate of increase of the plastic deformation, or flow, is therefore known, if the rate of decrease of the elastic deformation has been obtained, since the sum of the deformations remains constant.

As a check on the value of the Young's modulus, and to test the correctness of using it to relate the undissipated stress to the elastic recovery, an experiment, which was started in the same way as those already described, was carried out on the modified rack. After keeping the ink mark on the cross-wire of the microscope for about a minute, the stress was completely released and the elastic recovery observed. The magnitude of the stress just before it was released having also been observed, it was only necessary to obtain the mean cross-section in order to evaluate Y . The elongation of the cylinders when floated on mercury is not quite so even as when they are supported on rubber bands, and so the cross-section could not be determined very exactly. A value of 6×10^4 was obtained. It has been preferred to the value 4×10^4 obtained with the earlier method as any unevenness in the faces of the loaded

cylinder would cause an apparent increase in the deformation thereby giving too low a value for Y . It is to be understood, however, that this value is provisional in view of the difficulties of the experiment. The precise numerical value does not affect the general form of fig. 5.

Discussion.

4. In the foregoing sections it has been shown how the conception of the time of relaxation, which was used by Maxwell as a method of describing the viscous behaviour of a liquid, can be extended to cover the behaviour of a complex system such as a flour dough. An attempt will now be made to specify the type of internal structure indicated by the results of the investigation.

Firstly, it is clear that the dough contains elastic elements which form a connected structure and that the determination of Young's modulus has reference to these elements. Secondly, it is evident that the elements, though connected, are not joined securely, but slide past one another whenever a sufficient stress is operative. The viscosity which has been determined is mainly governed by the behaviour of a plastic film by which the elastic elements are connected. It is quite possible that the elements are capable of complete elastic recovery, but there is at present no criterion for testing this. The time of relaxation is a characteristic of the connected structure as a whole, and its value is as much determined by the elasticity of the elements as by the viscosity associated with their plastic junctions.

The considerable time (several minutes) which often elapses between the release of the stress and the cessation of contraction indicates the existence of another viscosity* which must be distinguished from that already considered. The fact that the dough exhibits elastic recovery at all shows that this second viscosity is of a relatively low order, for if the viscous resistance to change of

* This second viscosity appears to be of the same nature as that discussed by Shorter in his explanation of the slow extension of hair and wool fibres.† "The fibre contains elastic elements with very different degrees of damping, so that on the first application of an external force the more lightly damped elements extend, and, as time goes on, the extension of the more highly damped elements begins to show itself." And again, "We get (where a fibre is held stretched to a definite length) an apparent elastic relaxation, which, however, is very different from the effect contemplated in Maxwell's theory of viscosity. It is not the disappearance of a state of strain owing to molecular readjustments, it is merely the transference of a state of strain from lightly damped to highly damped elements."

† Shorter, S. A., 'J. Text. Inst.,' vol. T. 15, p. 207 (1924); 'Trans. Faraday Soc.,' vol. 20, p. 228 (1924); 'J. Soc. Dy. Col. Bradford,' vol. 41, p. 212 (1925).

shape were greater than that involved in the dissipation of internal stress, the stress would be dissipated before the dough had made any appreciable recovery. The second viscosity may be associated with the medium in which the elastic elements are embedded, but we cannot rule out the possibility of its being somehow connected with the elastic elements and their system of connection.

In relating these deductions to the known structure of the dough one may safely identify the elastic elements with the protein part of the flour. That the elements form a connected structure is confirmed by the fact that the starch and the other constituents of the flour can be washed out of the dough without breaking up the gluten. That the slowness of the elastic recovery is partly due to the presence of the starchy aqueous medium in the dough is indicated by the fact that the elastic recovery is more rapid in washed gluten than in the dough itself. The recovery of washed gluten is, however, not instantaneous, so that part of the second viscosity must be attributed to the gluten.

Our thanks are due to Professor G. I. Taylor, F.R.S., for his advice on the choice of data for inclusion in this paper, and to Dr. B. A. Keen for helpful criticism; also to Dr. E. A. Fisher, Director, and to Dr. P. Halton of the Research Association of British Flour Millers who have kindly provided the flours used in this work, and have given us much useful technical information.

Summary.

(1) An extended significance is given to Maxwell's "time of relaxation" and this has been used in quantitatively describing the viscous and elastic behaviour of flour dough.

(2) The length of the time of application of a stress in relation to the corresponding time of relaxation determines what proportion of the deformation is elastic (recoverable) and what proportion plastic (non-recoverable).

(3) This fact is illustrated by a comparison of the behaviour of dough in the "pachimeter" and on the "rack," the behaviour in the "pachimeter" (rapid stressing) being paralleled by that exhibited in a ballistic experiment.

(4) The decay of internal stress in pieces of dough which had been stretched out and held stretched has been followed, and the times of relaxation, and the corresponding viscosities have been evaluated for a series of stresses.

(5) Dough shows a phenomenon similar to the hardening of metals under working as a result of which the time of relaxation and the viscosity for a given stress depend on the total deformation.

The internal structure of the dough thus revealed is briefly considered.

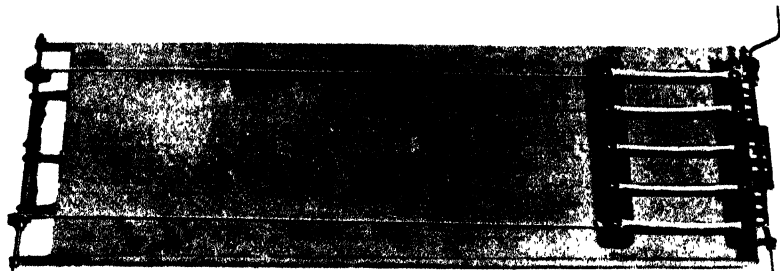


FIG. 8.

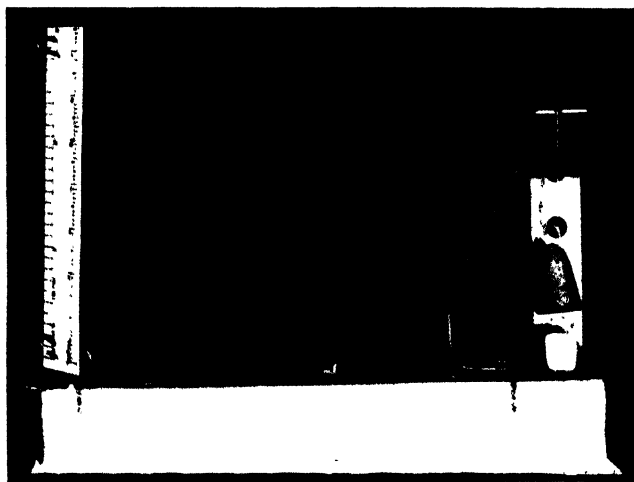


FIG. 9.

The Relationship between Viscosity, Elasticity and Plastic Strength of a Soft Material as Illustrated by some Mechanical Properties of Flour Dough.—II.

By ROBERT KENWORTHY SCHOFIELD and GEORGE WILLIAM SCOTT BLAIR.

(Communicated by Sir John Russell, F.R.S.—Received October 1, 1932.)

In an earlier communication* Maxwell's "time of relaxation" was given an extended and more general definition so that the conception might be used in describing the behaviour of plastic substances. From a study of such materials in steady flow it is well known that the viscosity defined as the ratio of the shearing stress, S , to the velocity gradient or rate of shear, G , is not a constant but usually decreases as S increases. The time of relaxation, t_r , is related to the viscosity, η , thus

$$t_r = \eta/n,$$

n being the rigidity modulus. Since n is normally independent of the stress,† t_r and η show parallel variations.

For ordinary fluids t_r is very small and no way has yet been devised for measuring it. In flour dough, however, we have a material in which high viscosities are combined with a low rigidity modulus, and consequently the relaxation of internal stress is slow enough to be easily followed experimentally.

* 'Proc. Roy. Soc.,' A, vol. 138, p. 707 (1932).

† p. 566.

Observations made on cylinders of dough which had been stretched to various extents showed that the relaxation time (and hence the viscosity) depends on the degree of stretching as well as on the stress.



FIG. 1.

It appeared desirable to obtain confirmation of this double dependence of viscosity on the extent of shearing as well as on the shearing stress by a more direct method. For this purpose, a study was made of the rate of elongation of cylinders of unyeasted dough hung vertically by their upper ends and allowed to extend under the action of gravity. In carrying out these observations it has been found convenient to mark on the dough cylinders a series of fine parallel lines accurately spaced 1 mm. apart. The marks were made by successive turns of a fine wire wrapped round a frame, which are wetted with enamel, the marks remaining wet long enough to be subsequently printed off on to a strip of duplicator paper. This method has the advantage of enabling an instantaneous record to be made of the deformation of a series of elements throughout the length of the dough cylinder. The recording is rapid and permanent, and the print (which may be called a rheogram) is available for whatever analysis appears suitable, fig. 2.

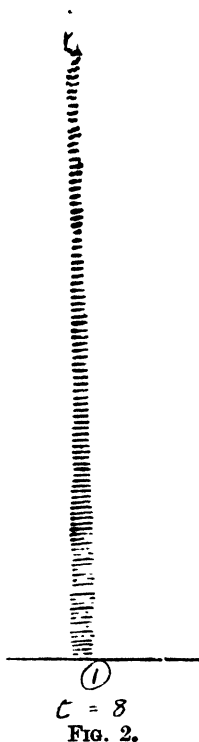
In obtaining the data which is about to be discussed, a number of precautions were taken :—

- (1) *Moisture Content.*—The doughs used had a moisture content such that when they were pressed firmly on to a glass plate they just did not stick appreciably to it. At the first mixing, slightly insufficient salt solution—strength 2.5 per cent.—was added to the flour, and after half an hour a little more was kneaded in so as to produce the desired condition. If, on thoroughly kneading at the end of a further half-hour, the moisture condition was judged to be correct, the dough was considered to be satisfactory for testing. In order to prevent drying during the test, the shaping, and marking of the cylinders was carried out as quickly as possible and while extending under gravity they were hung inside large boiling tubes containing a little water, see fig. 1.
- (2) *Shaping the Cylinders.*—Each of the pieces into which the dough was divided was forced through a short metal tube attached to a wider tube fitted with a plunger. In order to prevent avoidable straining, the “gun” was held vertically, the cylinders being extended downwards. Each cylinder as it was formed was detached and held by its

upper end which was then pressed firmly on to the support provided, see fig. 1. The diameter of these cylinders, about 7 mm., was surprisingly uniform except for a "blob" at the end, which was always cut off. The length used for the test depended on the nature of the dough, and on the time allowed for the extension, the aim being to use the longest cylinder that would not break off prematurely. In practice the lengths varied from 4 to 12 cm.

- (3) *Elastic Deformation.*—So long as the dough cylinder is hanging vertically, it is subject not only to plastic flow, but also to an elastic deformation which could be recovered by placing it horizontally. This recovery will only proceed to completion on a frictionless support like a mercury bath. It was found convenient to apply the marker and also to print off the rheogram with the dough lying horizontally on the wooden back B, but in neither case is the elastic deformation recovered owing to the tendency of the dough to stick lightly to the back as soon as it touches it. The elastic deformation was generally small compared with the plastic deformation, and as it was present both at marking and at printing, it cannot appreciably have affected the results.

- (4) *Printing the Rheograms.*—As a certain degree of pressure is needed when printing the rheograms which somewhat flattens the cylinder it was feared that the marks on the print might not faithfully reflect the state of affairs before the paper touched the dough. Such fears are, however, allayed by an examination of the rheograms themselves, fig. 2. The clearness of the impression makes it evident that no movement of the *surface* of the dough occurs once it has touched the paper. Before printing off, a line is ruled on the paper which is placed against the lower end of the dough cylinder when taking the print. This line provides the zero for computing the stress.



Although the apparatus and procedure are simple, care is needed in the manipulation lest the test cylinder be accidentally strained at some stage. So easy is it to spoil an experiment that the cylinders were usually tested in

triplicate. In the case of the data about to be discussed, one of each of the three sets had to be discarded leaving only duplicate rheograms for the final analysis.

When analysing the rheograms it is not necessary to know the dimensions of the cylinders, provided that they were initially of uniform cross-section. Except within a few millimetres of the support, the behaviour of any element is governed exclusively by the original length of the dough which hung below it. The top two or three marks are usually distorted and are always disregarded. In evaluating the shear and the shearing stress, use is made of the well-known principle (already employed in the earlier paper) that an elongation of a material which does not change its volume may be expressed as the resultant of two shears each equal in magnitude to the elongation, while the corresponding shearing stresses are equal to one-third of the tensile stress per unit area. The extensions involved here are sometimes several-fold, so that it appears better to express the elongation, and hence the shears, in an element of which the original length, l_0 , has increased after time, t , to l ; as $\log_e l/l_0$ rather than as $l - l_0/l_0$ (although, of course, the two expressions are equal for small elongations). The tensile stress per unit area acting over the meridian cross-section of this element was equal to $g\rho L_0$ where ρ is the density and L_0 the (initial) distance of the section from the lower end of the cylinder. This distance can still be ascertained after the elongation has taken place by counting up the markings. The elongation is accompanied by a proportional shrinkage of the cross-sectional area, so that the tensile stress at time t is $g\rho L_0 l/l_0$. Hence the mean shearing stress equals $\frac{1}{3} g\rho L_0 (1 + l/l_0)$ under which the dough suffers a mean rate of shear of $\frac{1}{t} \log_e l/l_0$.

In fig. 3 the mean rate of shear is plotted against the mean shearing stress for three times-of-hanging of cylinders all formed from pieces of the same dough and tested in rapid succession. The flour was a good bakers' mixture. A value of 5 mm. was selected for the length, l_0 , of an element, and l was found by determining the distance between each mark and its fifth neighbour. Each point is the result of a measurement of this kind. Two rheograms were obtained for each of the three times-of-hanging, and the points from all six are shown.

The lack of coincidence between the three sets of points shows that the rate of shear under a given stress is not uniform but diminishes as the shearing proceeds. It is very important to bear this fact in mind when seeking to interpret the curves. Apart from this fact their negative curvature, which is

particularly marked for the 8 min. curve, would be very surprising, involving an increase of viscosity with increase of stress. This curvature is the result of the double dependence of viscosity on stress and shear. The position emerges more clearly if sets of points corresponding to equal shears are picked out on the three curves. One such set is connected by the broken curve. This evidently leaves the axis of the abscissa at about $S = 800$ (since below this

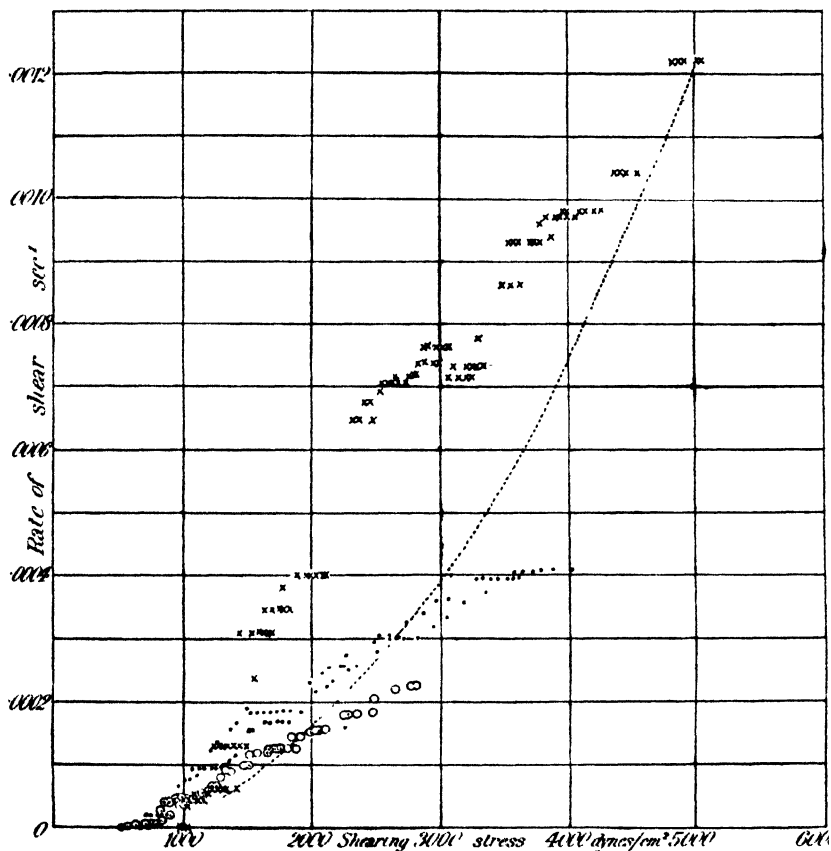


FIG. 3.—○ $t = 64$; • $t = 32$; × $t = 8$ minutes.

stress the shear is zero for all three times) and thence shows a consistent upward curvature. A family of such curves could be drawn each having the same form.

In order to evaluate the viscosities, the variation of shear with time for a series of constant mean stresses has been traced in fig. 4, the positions of the points being obtained by interpolating on fig. 3. The slope of one of these

at any particular point, gives the rate of shear under that stress after a shear measured by the ordinate has taken place. The figures given in the table for shears of 2.5, 4.1, and 7.0 were obtained in this way by dividing each

Shear.	0.25	0.41	0.70	0.58
Stress dynes/mm. ² .	Viscosities from rheograms.			Viscosity from relaxation times.
15	1.6×10^7	2.4×10^7	—	2.1×10^7
20	0.9×10^7	1.7×10^7	—	1.4×10^7
25	0.7×10^7	1.6×10^7	2.3×10^7	1.1×10^7
30	—	1.2×10^7	2.1×10^7	0.8×10^7
35	—	0.9×10^7	1.8×10^7	0.6×10^7
40	—	0.8×10^7	1.6×10^7	0.5×10^7

shearing stress by the corresponding rate of shear. These viscosities are of the same order of magnitude and show the same kind of variation with stress and shear as those deduced in Part I, fig. 5. A detailed comparison shows,

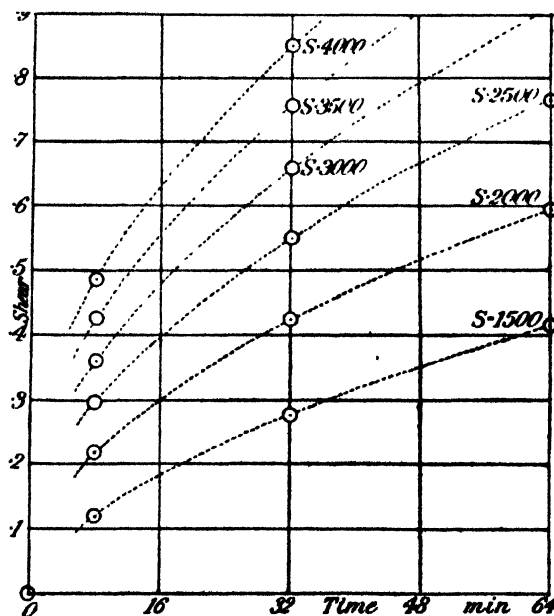


FIG. 4.

however, that the values obtained by the earlier method are consistently lower. As the new flour, though very similar, was not identical with that used in the former experiments, a set of observations of the relaxation of stress was

carried out on a dough cylinder made from the new flour (the old flour being no longer available). The measurements were carried out in the way described in Part I (*loc. cit.*) and the viscosities which are given in the last column of the table were obtained by finding the relaxation times ($= \frac{1}{d(\log_e S)/dt}$) for a series of stresses, and multiplying by the rigidity modulus ($= \frac{1}{3}$ Young's modulus). An extension of 80 per cent. was used, which falls between those used in obtaining the curves of fig. 5 of Part I. The corresponding shear of 0.58 also lies within the range covered by the rheogram figures.

The new values fall into line with the old. As will be seen they are only about half what would be obtained by interpolating between the figures for shears of 0.41 and 0.70. They rest, it is true, on the use of 2×10^4 as the rigidity modulus. This is admittedly a "round" figure, but it is unlikely to be in error by as much as a factor of 2*. There are other experimental and computational uncertainties, but none appears serious enough to account for the difference. When it is noted that the viscosities vary threefold for only modest variations of stress and shear it will be realized that the values are very sensitive to changes in the condition of the dough. It may be that the results differ because the shearing recorded in the rheograms was slow and steady in contrast to the rapid preliminary shearing given to the cylinders in the earlier method. As was noted in Part I a considerable proportion of the elastic recovery of a dough which has been strained for a long time is of the nature of a creep while the whole of the recovery from a short strain is comparatively rapid, indicating that during long periods of strain internal adjustments occur which take some time to readjust when the external stress is removed. It may be that these internal adjustments, which would have more opportunity of taking place in the rheogram method, have as much to do with the variations of viscosity as the shear associated with the alteration of external form, but such a hypothesis requires further test before it can be advanced with confidence. While reserving this point for further investigation we appear justified in taking the general concordance of the two sets of figures as substantiating the correctness of the relationship

$$\eta = t_r \cdot n.$$

In a general way the results from the rheograms show an interesting correspondence with those of Trouton† for pitch, though there are contrasts in the

* *Note.*—p. 566.

† 'Proc. Roy. Soc.,' A, vol. 77, p. 426 (1906).

magnitudes concerned. The stresses used by Trouton were considerably larger, and the rate of shear for a given stress approached constancy after a much smaller degree of shearing. Trouton stated that after the lapse of about half an hour under a constant stress a steady rate of shear was reached, but the data shown in his fig. 2, p. 428, are consistent with the view that a decrease was going on during the whole of the experiment. It is also interesting to compare his fig. 3, p. 429, with our fig. 3. Although he draws a straight line in his graph, his points indicate a negative curvature just as do ours in the case of dough. In both cases the curvature is only negative above a certain stress limit. For the dough, the curves start from the origin and remain practically coincident with the axis of the abscissa until somewhere between $S = 600$ and $S = 1000$, they then take a very steep upward bend after which the gentle negative curvature sets in. The upward bend marks the yield value, the corresponding stress measuring the shearing strength of the material under the conditions of the experiment. Below this stress no detectable flow takes place during the time of the experiment, and the material behaves like a solid.

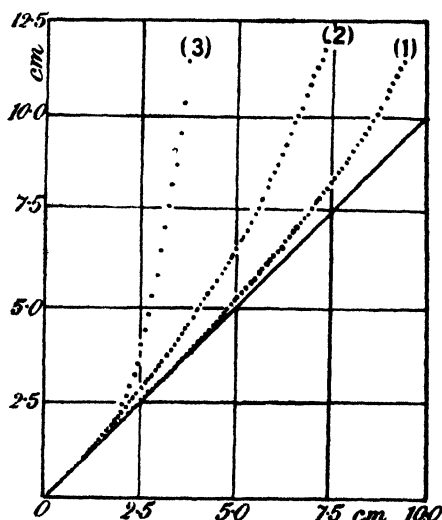


FIG. 5.—(1) Manitoba flour ; (2) Baker's mixture ; (3) English flour.

Although the foregoing analysis is needed to ascertain the factors upon which the rate of flow of a dough depends, a much less elaborate treatment suffices in many cases to distinguish doughs by their flow properties. Fig. 5 has been constructed by placing each of the three rheograms in turn along the axis of the ordinate and plotting the marks in turn against successive millimetre divisions along the abscissa. If no flow had taken place the result

would have been a line from the origin, of slope unity, and the aggregate flow in 20 minutes is shown by the departure of points from this line. This way of plotting easily differentiates the three flours in question, but the capacity of the method to distinguish the small differences which are of importance in baking has still to be determined. The outlook in this direction is, however, distinctly hopeful, as, from the point of view of the stresses used and their times of application, the conditions of the test correspond closely to those ruling inside a dough that is distending under the action of yeast.

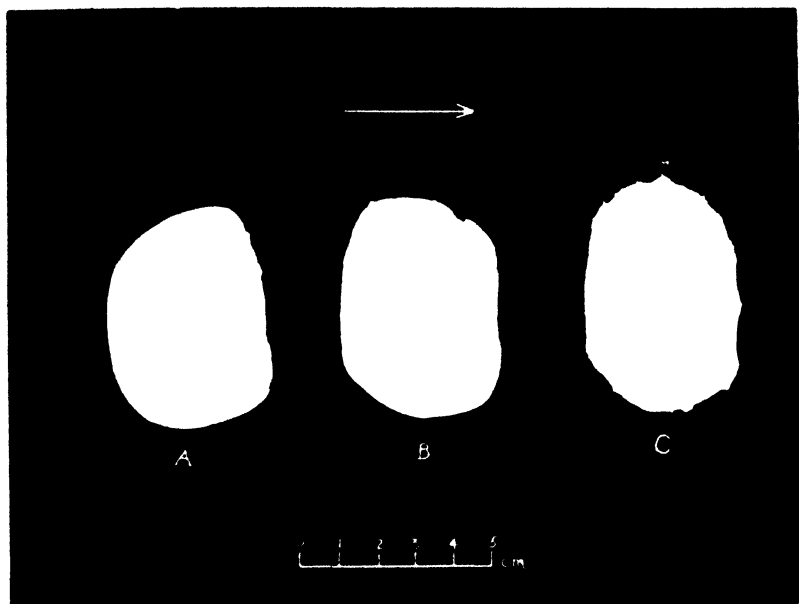


FIG. 6.

The hardening of a dough by shearing was independently demonstrated by a simple experiment. Three doughs were made up *with yeast* and kneaded well. Each was then pulled out and folded over a number of times, care being taken that the elongation and folding were always made in the same direction. The final fold was made so as to give the dough a form as nearly cubic as possible, finishing touches being given by slight pressure of the thumb and fingers. As the photograph, fig. 6, shows, the swelling was uneven, the smaller expansion occurring in the direction in which the dough had previously been stretched, as shown by the arrow. Dough B was at the standard moisture content, A being a little wetter, and C a little dryer.

Summary.

The dependence of the viscosity of a flour dough on the shear which has taken place as well as on the shearing stress is brought out by a series of observations on the rate of shear in cylinders of unyeasted dough hung vertically and allowed to elongate under the action of gravity.

The deformations were recorded by marking a millimetre scale in enamel on the surface of the dough cylinders, and, after elongation had proceeded for a measured time, printing the deformed scale off on to a strip of duplicator paper. The print has been called a rheogram.

The agreement between the viscosities determined directly in this way and those obtained indirectly in Part I is satisfactory as substantiating the theory that the viscosity is equal to the product of the rigidity modulus and the relaxation time.

The conditions of test correspond closely with those ruling inside a dough distending under the action of yeast, but whether the method is capable of distinguishing the small differences which are of importance in baking has still to be determined.

[*Note added in proof, January 11th, 1932.*—Further work, of which the results have been submitted for publication as Paper III of this series, has shown that, although n is far less variable than η , it is not exactly constant. (cf p. 557, lines 9 and 10.) Since writing the statement on p. 563 to the effect that the value of 2×10^4 for the rigidity modulus used to compute viscosity from relaxation time “is unlikely to be in error by as much as a factor of 2,” the authors have concluded that 2×10^4 , although a good mean value, is not that most appropriate for this computation. Using the value which the latest experiments have shown to be applicable to the conditions of stress relaxation, a close agreement is found between the viscosities calculated from the relaxation times and those obtained from the rheograms.]

The Relationship between Viscosity, Elasticity and Plastic Strength of a Soft Material as Illustrated by some Mechanical Properties of Flour Dough.—III.

By ROBERT KENWORTHY SCHOFIELD and GEORGE WILLIAM SCOTT BLAIR.

(Communicated by Sir John Russell, F.R.S.—Received January 2, 1933.)

The equation

$$\eta = n \cdot t_r \quad (i)$$

connects the viscosity, η , with the rigidity modulus, n , and the time of relaxation, t_r . In the case of simple fluids, for which the equation was originally given by Maxwell, the dissipation of shearing stress is so rapid that neither n nor t_r has been measured, so that the relationship has only a theoretical interest.

In the first paper of this series* it was shown that in flour dough stress dissipation proceeds at rates that can readily be followed experimentally. The "time of relaxation," t_r , was given an extended significance, and defined in such a way as to be applicable to plastic materials like dough for which η is not a constant. A series of values for the viscosity was obtained with the aid of equation (i).

In the second paper† a description was given of a method by which a record or "rheogram" can be obtained showing the amount of flow that has occurred in a given time under stress. In this way another series of viscosity values was obtained. A comparison of the two sets showed a satisfactory agreement so far as order of magnitude was concerned, but it revealed quantitative discrepancies which made a further investigation desirable.

In both papers the fact that the viscosity is dependent on the total strain as well as on the stress was the subject of comment. Flour dough thus exhibits a behaviour reminiscent of "work-hardening" in metals, and it is evident that we can only expect agreement between values of η in cases where the "history" of the specimens has been the same. Further study has revealed the existence of two more effects which have close parallels in the behaviour of metals, namely, elastic after-effect and elastic hysteresis.‡ It is shown

* 'Proc. Roy. Soc.,' A, vol. 138, p. 707 (1932), referred to as Paper I.

† 'Proc. Roy. Soc.,' A, vol. 139, p. 557 (1933), referred to as Paper II.

‡ Cf. Nadai, "Plasticity," McGraw Hill Book Co., New York (1932).

below that by taking due account of these properties the seemingly conflicting results of Paper II fall into line.

Elastic After-effect.

The apparatus was a modification of that used to follow the relaxation of stress and described in Paper I. A cylinder of dough, about 15 cm. long and 0.7 cm. diameter, was floated on a mercury bath. Two small scales, graduated in quarter centimetres and tenths, were attached one at either end of the dough by means of cork "chairs" which adhere readily to it. To one scale (scale A) was fastened a thin strand of rubber, about 20 cm. long, the other end being anchored to a stout pin sticking up in the trough. To the other scale (scale B) was attached a piece of sewing cotton, the other end of which was wound on a small winch controlled by a worm and crank. Two low-power microscopes were trained one on either scale. One-tenth part of each small division could be estimated, so that a movement of 0.0025 cm. could be detected with certainty, fig. 1.

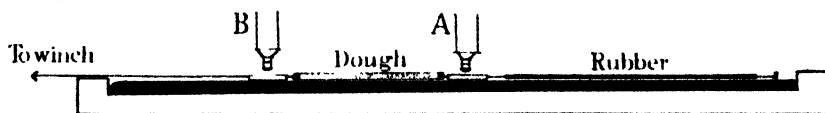


FIG. 1.

The position of scale A is a direct indication of the stress. Calibration was effected by placing the trough erect, when empty, and hanging weights on the lower end of the scale, due allowance being made for the weight of the scale and rubber in obtaining the zero. The elastic properties of the rubber, although not perfect, were found to be sufficiently satisfactory. For extensions up to 10 per cent. a constant factor of 690 dynes per scale division was found. To obtain the extension of the dough cylinder, the shift of scale A must be subtracted from the corresponding shift of scale B.

The doughs were made up in the way described in Paper II, the moisture content being so adjusted that the dough did not stick appreciably to a glass plate when pressed firmly against it. The doughs were allowed to stand for $1\frac{1}{2}$ hours before use, and the cylinders were formed by extrusion from a "gun." The part of the mercury trough occupied by the cylinder was flanked by a strip of wet felt and covered by a glass-topped frame to minimize drying.

When the tensile stress on a dough cylinder is increased, a point is reached at which the plastic strength is exceeded and plastic (non-recoverable) extension occurs. If the tensile stress is below the plastic limit, an extension, due to a

small increase in stress, appears to be wholly recoverable on restoring the stress to its former value, provided that sufficient time is allowed. Fig. 2, *a* and *b*, is the record of such an experiment. The dough had been under a stress of 4700 dynes/cm.² for some minutes (the plastic limit in this case being about 5000 dynes/cm.²) and neither scale was moving appreciably. The handle of the winch was then given a turn which caused the scale B to move 0.41 divisions.

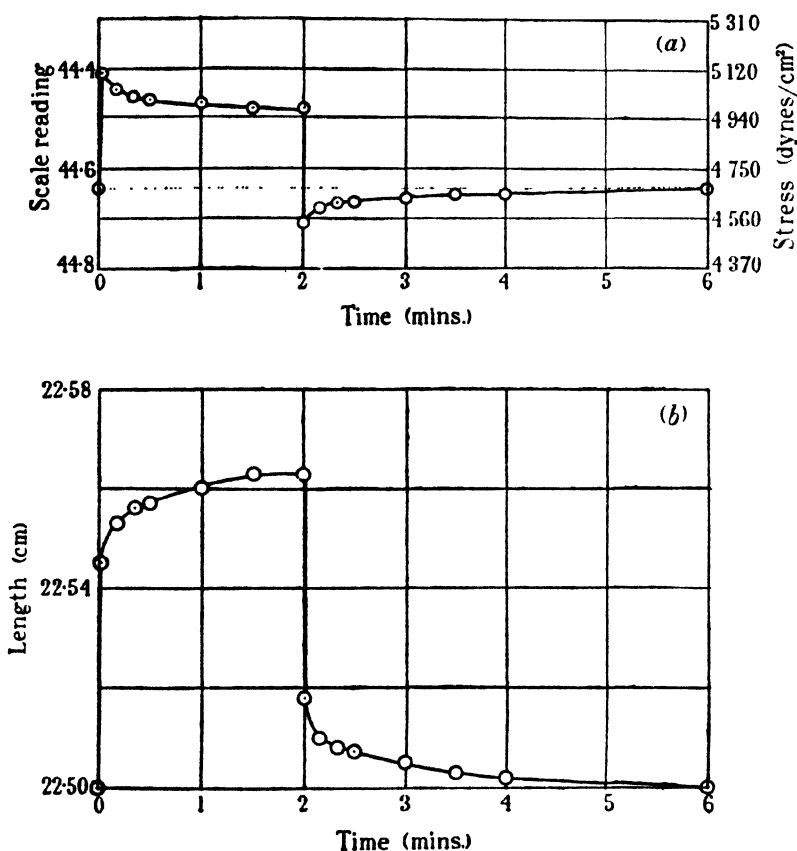


FIG. 2.

After two minutes a reverse turn was given to the crank which restored the scale to its original position. Fig. 2, *a* shows the movement of scale A which, as already noted, is a direct indicator of the stress, and of which the shift must be subtracted from 0.41 (the shift of scale B) during the first 2 minutes, and from zero subsequently, in obtaining the elongations shown in fig. 2, *b*. It will be seen that the value obtained for the rigidity modulus by dividing

one-third of the change in tensile stress by the corresponding elongation, depends materially on the time allowed. If the first reading obtained after turning the winch is used, the value is $n = 7.7 \times 10^4$; after 2 minutes it is $n = 4.3 \times 10^4$. It will be seen that both the stress and the strain returned to their original value so that no perceptible plastic flow occurred during the period occupied by the experiment. The phenomenon exhibited is essentially that of elastic after-effect.

Fig. 3 shows the same thing at a higher stress, namely, 5400 dynes/cm.². Here the effects of slow plastic flow and of elastic after-effect are superimposed.

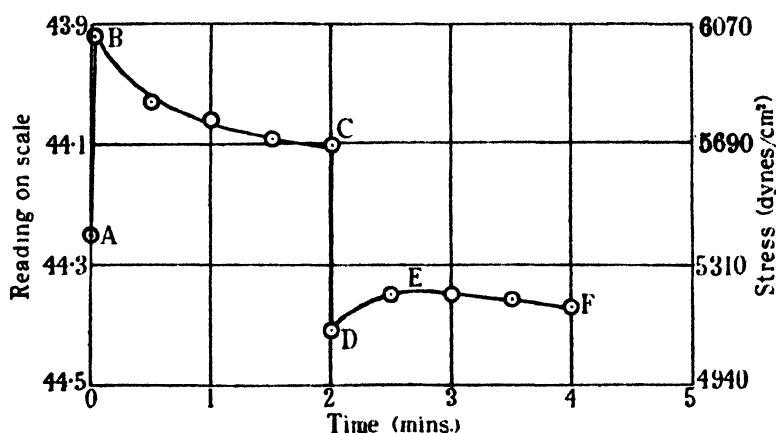


FIG. 3.

Elastic after-effect was also studied by first extending a dough cylinder at a uniform rate by driving the winch from a suitably geared electric motor and then suddenly releasing the stress altogether by burning the cotton. Fig. 4 shows the variation of length with time in a typical experiment. According to the Maxwellian theory, the rate of fractional elongation de/dt is related to the shearing stress, S (which is one-third the tensile stress, s , for this material), thus

$$\frac{de}{dt} = \frac{1}{n} \frac{dS}{dt} + \frac{1}{\eta} \cdot S. \quad (\text{ii})$$

At the point B in fig. 4 the stress was suddenly reduced to zero. Equation (ii) indicates that a large negative de/dt is to be expected momentarily, but that de/dt should immediately afterwards become zero. Actually de/dt maintained an appreciable negative value for many minutes during which both S and

dS/dt were zero. Such a case can only be covered by an extension of equation (ii), such as

$$\frac{de}{dt} = \left(\frac{1}{n} \cdot \frac{dS}{dt} - \frac{d\alpha}{dt} \right) + \frac{1}{\eta} \cdot S, \quad (\text{iii})$$

in which α represents the influence of elastic after-effect.

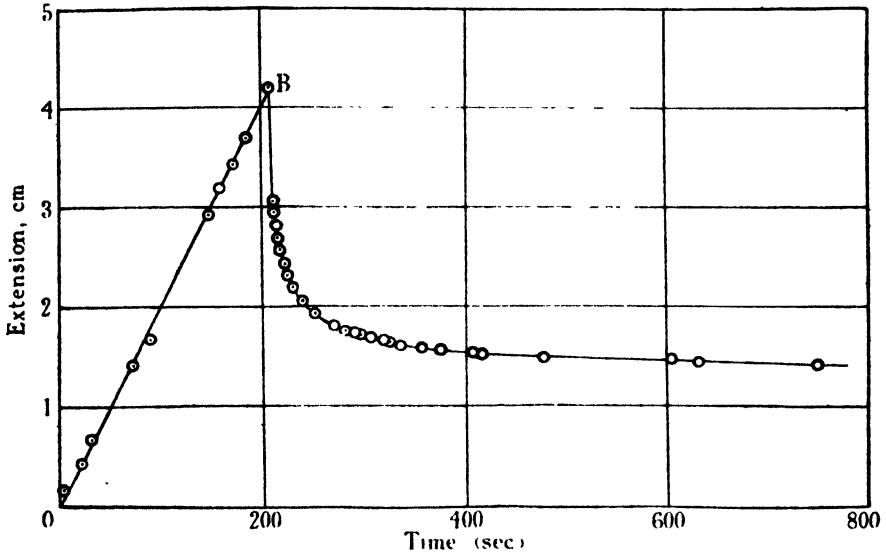


FIG. 4.

Applying this relation to the case illustrated in fig. 2, $\frac{1}{\eta} \cdot S$, which represents the rate of plastic flow, may be neglected, and we obtain by integration

$$\Delta e = \frac{1}{n} \Delta S - \Delta \alpha.$$

As a steady condition is approached when the system is left undisturbed, it is reasonable to regard α as tending to zero under these circumstances. Interpreted in this light, fig. 2 indicates that on rapidly increasing the stress, α assumes a positive value which falls gradually towards zero so long as there is no further abrupt change in stress. Conversely, a rapid decrease in stress imparts a temporary negative value to α .

The fact already noted that in fig. 3 the effects of plastic flow appear simply to be superimposed on the elastic effects shown in fig. 2, is reflected in the form of equation (iii) which shows de/dt to be the simple sum of an elastic part (within the bracket) and a plastic part. A particularly interesting feature

of fig. 3 is the spontaneous rise of the stress to a maximum from D to E. An unthinking use of the expression

$$t_r = -S \frac{dS}{dt} \text{ (at constant elongation)} \quad (\text{iv})$$

would suggest that the relaxation time had a negative value in this region. Reference to equation (iii) shows, however, that when de/dt is zero, $t_r = \eta/n$ is only equal to $-S \frac{dS}{dt}$ when $d\alpha/dt$ is zero; and this only occurs when no rapid change of stress has taken place for some time. The definition of t_r , adopted in Paper I and embodied in equation (iv), is therefore subject to this limitation. Furthermore, of the two values for n , given in connection with fig. 2 for the modulus, it is now clear that the lower one, 4.3×10^4 , must be preferred when relating η to t_r .

Elastic Hysteresis.

An experiment such as that of fig. 4 can also give a value for n if, in addition to a determination of the total contraction, a measurement is made of the stress just before burning the cotton. Table I summarizes the results of three such experiments. The striking fact to be noted is the smallness of the values found for n in comparison with that deduced above from fig. 2. The difference cannot be put down to elastic after-effect.

Table I.

s .	l_1 .	l_2 .	n .
5200	18.1	16.0	1.40×10^4
5400	19.7	17.4	1.45×10^4
5200	20.3	18.1	1.61×10^4

s is the tensile stress, n , the rigidity modulus, and l_1 and l_2 the lengths of the dough under stress, and after recovery respectively.

The origin of this discrepancy became apparent from a further experiment. A dough cylinder was first extended at a slow uniform rate by about 2.5 cm. so as to remove any tendency to curl, and was then held extended for about 5 minutes to allow the stress to fall to a value in the neighbourhood of the plastic limit, at the end of which time its rate of decrease was quite slow. This condition is indicated by the point A on fig. 5.

The stress was then released by stages. Fifteen seconds was allowed between each turn of the crank, the stress recorded being that at the end of each 15-seconds period. It was necessary to fix some time interval of this kind in order that the small influence of elastic after-effect should be spread evenly over the experiment. At B nearly all the stress had been released and it was then increased in the same way to C; and the cycle twice repeated. The lateral shift of the loop at each repeat is evidence that plastic flow occurred

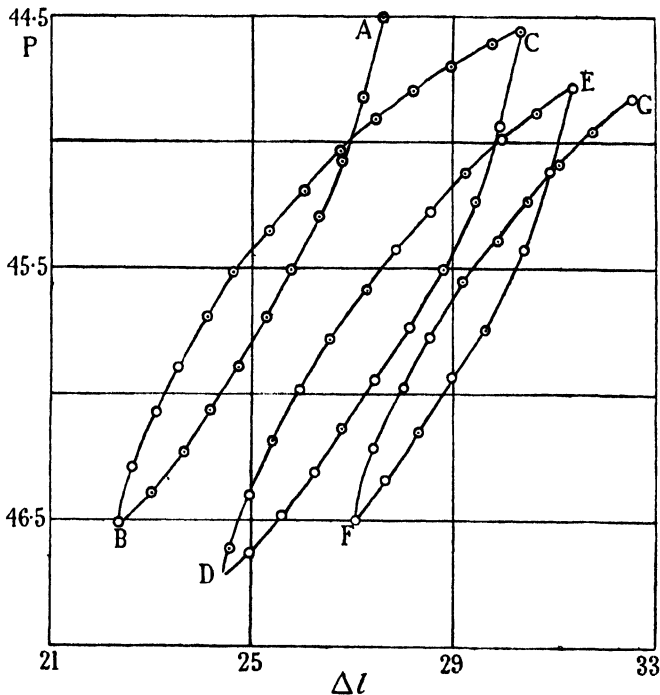


FIG. 5.

at the higher stresses. It appears safe to assume, however, that this complication does not arise in the lower portion of each loop. In following any *continuous* curve it is found that the modulus connecting the change of stress with the corresponding change of length always *decreases*; but that at each *discontinuity* where the sense of the stress change alters, the modulus abruptly *increases* very considerably. At the points B, D and F the modulus changes from about 1×10^4 to 4×10^4 .

The modulus obtained from fig. 2, using 15 seconds as the time interval, should evidently be compared with the highest values obtained from fig. 4 since both refer to the condition just after a change in sense of stress variation.

The moduli quoted in Table I, as well as those cited in the earlier papers of this series, are in a sense mean values corresponding to a change such as that from A to B, C to D, or E to F on fig. 5, and we should expect these values to be small. The exact magnitude of such a mean value will evidently depend, among other things, on the magnitude of the stress change, and will tend to decrease as this increases. The recognition of this phenomenon, which is essentially a case of elastic hysteresis, enables a rational explanation to be formulated for the marked inconstancy of the modulus. It also makes it necessary to reconsider the value previously adopted for the modulus when deriving the viscosity from the relaxation time.

Test of the relation $\eta = nt_r$.

The presence of elastic after-effect and elastic hysteresis adds considerably to the difficulty of devising an experimental check on equation (i). The only satisfactory way would appear to be to measure all three quantities in rapid succession on the same piece of dough. A number of experiments of this kind were carried out with the apparatus slightly rearranged in the manner shown in fig. 6. A scale (scale C) was inserted at the right-hand end of the rubber strand and held by a cotton wound on a hand-controlled winch. The winch at the left-hand end (off the diagram) was connected to an electric motor through a suitable gearing provided with a "clutch" by means of which the winding could be started or stopped at will.



FIG. 6.

During the first part of each experiment the motor-driven winch was allowed to pull the dough out slowly, the rate of extension being determined by observing the motion of an index on the cotton as it moved over a suitably placed millimetre ruler. At the same time, scale A was kept under observation. With this arrangement the stress is given by the difference of the readings of scales A and C, but since during this part of the experiment the position of scale C was not altered, the movement of scale A was a direct indication of the rise in the stress. After a while the increase of stress became very slow, and then when a suitable division of scale A exactly coincided with the cross-wire of the observing microscope, the clutch was thrown out, the time being noted. Simultaneously

the hand-winch was released by one turn. This caused both the scales to shift. Scale C moved in direct response a distance of 0.19 scale divisions; scale A first moved rapidly to the left and then more slowly returned towards its former position. As soon as it reached its old position the crank was given a further turn, the time being again noted. The process was repeated a number of times. The method used here is essentially the same as that adopted earlier in following the relaxation of stress and already described in Paper I, but there is one important addition. With the former apparatus the movement of the end of the dough attached to the rubber strand could be observed but not measured. By *measuring* the extent of the rapid *elastic* reaction of the dough to the movement of the hand-winch a value can be obtained for the modulus. The evaluation of η , t_r , and n is most readily explained by taking a single experiment and working it out in detail.

Evaluation of η .—In a typical case the dough was first pulled out at a steady rate of 0.0154 cm. per second until its length was 25.3 cm. At this point $\frac{de}{dt} = \frac{0.0154}{25.3} = 6.1 \times 10^{-4} \text{ sec.}^{-1}$. Although the pull of the rubber strand had become steady, the cross-section of the dough was diminishing, so that the stress per unit area was rising. From the geometry of the case, $\frac{1}{S} \frac{dS}{dt} = \frac{de}{dt}$; hence the elastic part of the elongation, namely, $\frac{1}{n} \frac{dS}{dt}$, equals $\frac{de}{dt} \times \frac{S}{n}$. S , the shearing stress which is one-third the tensile stress per unit area of cross-section, was found from the scale readings and the dimensions of the cylinder to be $2.7 \times 10^3 \text{ dynes/cm.}^2$. The appropriate value for n we do not know exactly, but as the stress had been slowly rising from zero it was certainly low and probably not greater than 1×10^4 . This gives $\frac{1}{n} \frac{dS}{dt} = 1.6 \times 10^{-4} \text{ sec.}^{-1}$. Owing to the comparatively steady stress conditions, da/dt of equation (iii) will be negligible; hence the rate of plastic flow is simply

$$(6.1 - 1.6) \times 10^{-4} = 4.5 \times 10^{-4} \text{ sec.}^{-1}.$$

Dividing into S we have

$$\eta = \frac{2.7 \times 10^3}{4.5 \times 10^{-4}} = 0.6 \times 10^7 \text{ dynes . cm.}^{-2} \text{ . secs.}$$

Evaluation of t_r .—Equation (iv) for t_r holds as we have seen when there is no appreciable change in α . As soon as the clutch is thrown out the stress

starts to fall, somewhat rapidly at first and more slowly afterwards. After the first turn of the hand-winch 9 seconds elapsed before scale A returned to its original position. The stress change as given by the shift of scale C was 0.19 scale divisions and the mean stress in the same units was 2.67, hence

$$S / \frac{dS}{dt} = \frac{2.67 \times 9}{0.19} = 126 \text{ secs.}$$

As α must have been taking on an increasing negative value during this time, this figure will be a little below the true value for t_r . Reference to fig. 2 indicates that 0.19 scale divisions in 9 seconds is not an excessive rate, and suggests that the discrepancy will not be large. The series of values thus obtained were

$$126, 275, 445, 760, 1280, 1980 \text{ seconds.}$$

These are mean values, and an estimated value of

$$t_r = 100 \text{ seconds}$$

for the relaxation time immediately after throwing out the clutch seems reasonable.

Evaluation of n .—In calculating n from the rapid elastic reaction of scale A to the movement of the hand-winch, the influence of elastic after-effect is more serious. After the turn of the crank which immediately followed the throwing out of the clutch, the leftward movement of the scale was arrested by plastic flow in the dough after about 1 second, a time interval which must have been insufficient to allow the full elastic movement to occur. After the sixth turn more than 20 seconds elapsed before the scale resumed its rightward movement. It is not therefore surprising to find that n apparently changes from 11×10^4 at the first shift to 6×10^4 at the sixth. Owing to elastic hysteresis some fall in n is to be expected, but there can be little doubt that the second figure is nearer the true value of n immediately after the clutch was thrown out. This conclusion is confirmed by the value

$$n = 6 \times 10^4 \text{ dynes/cm.}^2$$

obtained from the ratio of the estimated values of η and t_r . The closeness of the agreement is partly fortuitous as round figures have been used throughout. In some of the other experiments of the same kind the concordance was not so close, but no case was found which, when due allowance had been made for the numerous uncertainties, provided clear evidence in conflict with the equation

$$\eta = n \cdot t_r \quad (i)$$

In the last analysis it appears doubtful whether this equation is capable of direct proof, seeing that η , n and t_r are all variable quantities, and it does not appear possible to measure all three actually simultaneously. It is perhaps true to regard equation (i) as defining t_r in terms of η and n which in their turn are defined by equation (iii). We may then take the above experiments as indicating that by using equation (iii) we do not obtain values for η and n which show inconsistent or unreasonable fluctuations.

The lack of agreement between the values obtained for η from the rheograms in Paper II and those calculated from n and t_r using the data of Paper I is no longer surprising. Undoubtedly the chief cause of the discrepancy is to be found in the value 2×10^4 used throughout for n . This is certainly a good *mean* value for the doughs used, but it is now clear that the conditions under which t_r is measured correspond to a part of the hysteresis loop in which n has a value appreciably above the mean. A value in the neighbourhood of 5×10^4 would accord better with the findings of this paper and also bring the two sets of figures into line. It will be noted that the viscosity found above, namely, 0.6×10^7 , is lower than the general run of the values given in the table in Paper II. This is to be expected since the tensile stress was 8100 dynes/cm.², which is higher than for any viscosity included in the table; the extension in the units used was 0.43.

Conclusions.

Taken together, our experiments seem to show that the mechanical properties of flour dough can be described by the equation

$$\frac{de}{dt} = \left(\frac{1}{n} \frac{dS}{dt} - \frac{d\alpha}{dt} \right) + \frac{1}{\eta} \cdot S. \quad (\text{iii})$$

n varies in a manner characteristic of elastic hysteresis. Consequently it is liable to increase abruptly when dS/dt changes sign, and is generally dependent on the history of the specimen. Direct measurements of n have been only possible at stresses below the limit of plastic strength, but indirect determinations obtained by dividing η by t_r have been made above it; and there is no evidence of any change in n in passing across this limit other than that to be anticipated from hysteresis.

α , as we have seen, is only of importance when abrupt changes have recently occurred in S . Like n , it does not appear to depend on the absolute value of S , but rather on its value relative to those which have obtained in the immediate past.

η shows quite a different behaviour. It is extremely sensitive to the absolute value of S . So rapidly does it increase as S is reduced, that only a narrow margin of stress separates the condition in which plastic flow is dominant from that in which it can scarcely be detected. Herein lies the justification for the use of the words "plastic limit" and "plastic strength." For, although a *precise* limit could only be defined by arbitrarily specifying a certain viscosity as marking the limit, no serious misunderstanding is likely to arise in practice. Furthermore, although η is strongly influenced by the previous history, it appears to be affected by factors quite distinct from those which control n . As we have seen, n is largely determined by the previous movements of S ; η , on the other hand, is mainly affected by the amount of flow that has taken place, and increases for a given value of S as the elongation proceeds. A series of experiments, of which the results are shown in fig. 7, showed clearly

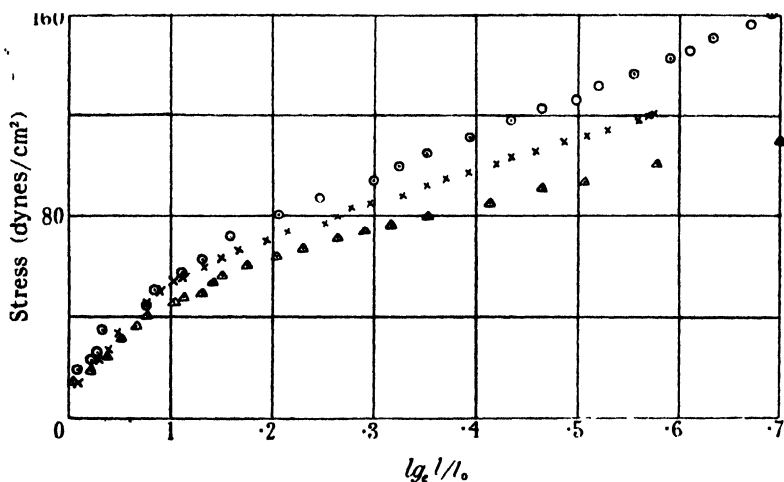


FIG. 7.

that the extent of this hardening is controlled by the amount of the elongation as well as by its rate. The apparatus as shown in fig. 1 was used, and the winch was driven at a steady rate by the electric motor, a different speed being used in each experiment. The similarity of the curves, for which the extreme speeds were as two to five, provides clear evidence on this point. It is interesting to note how similar is the behaviour exhibited in fig. 7 to that shown by soft metals, particularly at high temperature; the same can equally be said of fig. 5 (Nadai, *loc. cit.*).

In conclusion, an electrical analogy may prove helpful to some when considering the meaning of equation (iii), and its use in the various special cases

considered above. Using the formal analogy which exists between viscosity and electrical resistance, and between elasticity and electrical capacity, it may be said that the electrical behaviour of the system sketched in fig. 8 reproduces the essential mechanical properties of dough. Fig. 8, *a* represents the condition after the point B of fig. 4 at which the stress on the dough is suddenly released. In the electrical case it is supposed that an e.m.f. was first applied between A and B and that the system was then short-circuited. The current in R would cease at once and the condenser, C, would instantly discharge. The charge in *c* would take some time to leak through the high resistance, *r*. The branch *cr* is evidently responsible for the "after-effect" and will give a finite " α " whenever the e.m.f. across C differs from that across

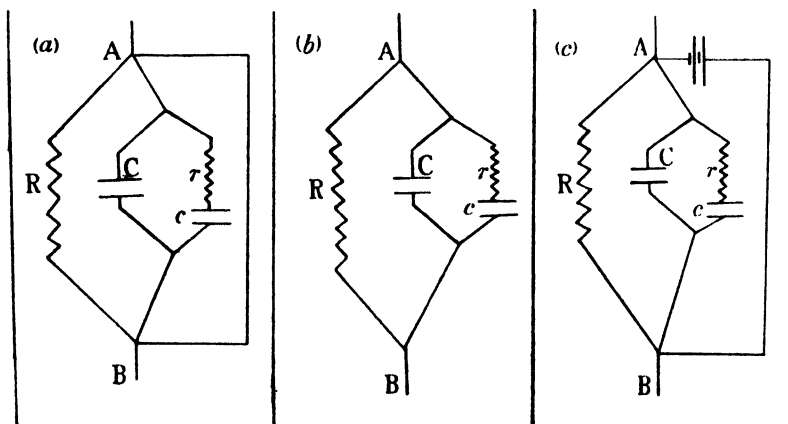


FIG. 8.

c, which will be the case after any abrupt change in the external e.m.f. In fig. 8, *b* the system after being subjected to an e.m.f. has been disconnected. This condition corresponds with stress relaxation at constant elongation. The condensers discharge through R; unless R is large compared with *r*, " α " will make its appearance. In fig. 8, *c* we have the analogy to conditions which furnished data for fig. 7, namely, the steady application of stress. To make the analogies closer, the resistances and capacities should be considered to be variable.

There is, however, an important contrast, in that the three elements which go to make up the mechanical system must be regarded as linked end to end and not "in parallel" as in the electrical case. The elastic elements in the dough, the behaviour of which is described by the symbols η and α , are presumably formed by the protein constituents, while the plasticity embodied in the symbol

η must be associated with the linkage between the elastic elements. The individual elastic elements appear to possess mechanical properties similar to those which Shorter and others* have found in hairs.

Summary.

A further study of the mechanical properties of flour dough has revealed the presence of two properties in addition to hardening, both of which are well known in the study of metals; namely, elastic after-effect and elastic hysteresis.

The first necessitates the addition of a term $d\alpha/dt$ to the Maxwell equation, which then becomes

$$\frac{de}{dt} = \left(\frac{1}{n} \frac{dS}{dt} - \frac{d\alpha}{dt} \right) + \frac{1}{\eta} \cdot S.$$

This term is only important when abrupt changes of stress have recently occurred.

The second property causes n to decrease steadily whenever dS/dt preserves the same sign for some time, and to increase abruptly when the sign of dS/dt is changed.

In Paper II it was shown that the viscosity, as determined from the rate of flow, agreed roughly, but not exactly, with that calculated as the product of the rigidity modulus and the relaxation time. It is now clear that the value adopted for n was a mean value, and differed somewhat from that appropriate to the conditions during stress relaxation. Due appreciation of this point renders the agreement quantitative.

* 'J. Text. Inst.,' vol. 15, p. 207 (1924); 'Trans. Faraday Soc.,' vol. 20, p. 228 (1924); 'J. Soc. Dyer Col. (Bradford),' vol. 41, p. 212 (1925).

THE DEGREE OF HUMIFICATION IN MANURES MEASURED BY THE USE OF HYDROGEN PEROXIDE

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Received for publication August 1, 1932

It has been shown by Robinson and Jones (4) that humified organic matter can be distinguished from non-humified by the use of 6 per cent hydrogen peroxide. An account is given in the present paper of the use of this reagent in determining the degree of humification in manures. Different workers have employed different concentrations of the reagent. McLean (2) made a thorough investigation with the reagent in various concentrations in estimating the organic matter in soils. Jones (1) used 6 per cent hydrogen peroxide in determining the degree of humification in farmyard manure. Humified or decomposed organic matter appears to be oxidized or rendered soluble by the reagent while the structural or undecomposed materials remain unaffected. It has been assumed by Jones that such a distinction exists in the case of farmyard manure between the decomposed material and the unaltered fiber of the feces and litter. In the present investigation the manures were obtained by artificial methods and no such assumption is made.

Richardson (3) holds that if a reagent is to be used for effecting a separation between humified and non-humified matter it should have a minimum of action on the unhumified matter. He observes that with most materials the greater part of the effect of hydrogen peroxide is simply a solvent action. This means in effect that² water alone can reproduce most of the loss by its solvent action. To test the validity of Richardson's statement similar samples of manure were treated simultaneously under identical conditions with (a) water, (b) hydrogen peroxide. The time required for the reaction with H_2O_2 to be completed, i.e. when frothing ceased, was first found. The samples were then treated with water for the same length of time with the same volume as peroxide. This gave a comparison between the solvent action of both H_2O_2 and water and also made evident the further action of the reagent over and above that of water. In each of the representative cases the loss of ash and the loss of organic matter due to extractions with both reagents were also compared.

¹ The author is indebted to Sir John Russell, director of the Rothamsted Experimental Station for placing at his disposal the facilities of the station. His thanks are due to Mr. E. H. Richards, head of the fermentation department and to Dr. S. H. Jenkins for their assistance and advice.

² With many materials.

In view of the differences of opinion held regarding the use of 3 per cent or 6 per cent hydrogen peroxide, both strengths were tried with chaffed oat straw and with the same straw rotted in the presence of ammonium carbonate. No appreciable difference was found between the results obtained in both cases. It was therefore decided to use 3 per cent hydrogen peroxide instead of 6 per cent in all the quantitative experiments.

EXPERIMENTAL

Oat straw was rotted under aerobic conditions at 35°C. with initial moisture contents of 60, 70, 80, and 90 per cent for each nitrogenous substance. Each bottle, containing 20 gm. of the air-dry straw, was supplied with 0.2 gm. of nitrogen in the form of inorganic salts such as ammonium carbonate, ammonium sulfate, and sodium nitrate, and organic substances such as peptone, casein, and urea. The bottles were incubated for one month and the contents mixed at frequent intervals. Whenever necessary, moisture was added but the manures were never allowed to become water-logged. At the end of 1 month the bottles were weighed and the moisture contents together with other analytical figures were determined. The loss of dry matter on rotting was then calculated and the extent of the decomposition found.

The total percentage of organic matter was determined by finding the "loss on ignition" on 1 gm. of the well-chopped manure dried at 100°C. The quantity of the manure available for analysis being small, about 1-gm. samples of the same dry manure were used for treatment with hydrogen peroxide. The material was gradually heated to boiling with 100 cc. of 3 per cent peroxide with stirring in beakers of 600 cc. capacity. For this reaction, 100 cc. of the reagent was found to be enough. When the frothing had ceased, which indicated that the reaction was complete, the contents of the beaker were made up to about 250 cc. with hot distilled water and boiled for 20 minutes. The contents were then filtered hot, first by decantation of the supernatant layer of the solution on a tared fluted filter paper. The residue was thoroughly washed with hot water till the filtrate was colorless, when it was finally transferred to the filter and dried at 100°C. It was then cooled in a desiccator and rapidly weighed, as the material absorbs moisture. The residue and filter paper were ashed together and the ash of the filter paper was deducted. The weight of the organic matter initially present being known, the amount lost by oxidation or by solvent action or from both causes can be obtained by difference. The total loss is obtained by subtracting the residue after H_2O_2 treatment from the weight of the dry manure before its treatment with the reagent. This total loss is always found to be more than the loss in organic matter, as it is likely that some of the inorganic material will dissolve out. The loss of organic matter on 100 gm. of the original material gives the degree of humification.

To test whether the loss due to the peroxide treatment was due to oxidation or to solvent action or to both causes in each of the representative cases, the

hydrogen peroxide extract was evaporated to dryness in weighed silica dishes on a water bath and then dried in a desiccator. The ash in the extract was obtained by ignition. The residue in the peroxide extract minus the ash of this extract gives the organic matter present in the extract. The total loss minus the peroxide residue gives the matter oxidized by the action of peroxide.

For comparing the action of water and peroxide, about 5 gm. of the wet samples were extracted with the same volume of water as peroxide under similar conditions. In the case of water extract direct filtration is slow and hence it was first filtered through a plug of cotton wool, and then in a Buchner funnel on a water suction pump. The residue was well washed with hot water, The filtrate was evaporated to dryness on a water bath, weighed, and the total extract was determined by igniting the dried residue.

To determine how the method worked with manures, three different types, which had been rotted under known conditions, were treated first. One

TABLE 1
Results expressed on 100 gm. of dry manure

	MOISTURE CONTENT	TOTAL O. M.*	O. M. AFTER H ₂ O ₂ TREATMENT	LOSS OF O. M.	TOTAL LOSS	DEGREE OF HUMIFICATION
	gm.	gm.	gm.	gm.	gm.	per cent
1	82.2	71.9	23.9	48.0	59.0	66.7
2	83.0	55.2	24.7	30.5	36.8	55.2
3	76.0	56.5	44.2	12.3	22.7	44.2

*O. M. = organic matter in this and following tables.

sample was a highly humified farmyard manure. The second was an artificial farmyard manure made from wheat and bean straw rotted with calcium cyanamide as the added supply of nitrogen, and was fairly well humified. The third was wheat straw alone also rotted with cyanamide. It did not appear to be well humified. The results of the treatment of the three manures with peroxide are given in table 1 and seem to agree with the appearance of the samples. The duplicate determinations agreed closely. The difference between the action of 3 per cent and 6 per cent hydrogen peroxide on undecomposed and decomposed straws is not appreciable, as can be seen from table 2.

The loss of organic matter in the case of undecomposed straw is about 20 per cent in both the treatments and in the case of both artificial manures the average loss amounts to about 30 per cent. As there was no difference in the amount of extractable matter obtained with the two strengths of peroxide, the 3 per cent solution was chosen for further experiments. The only noticeable difference was in the colors of the filtrates and the residues. The color in the case of 6 per cent was paler than in the case of 3 per cent. This color difference can be attributed to the bleaching action of the peroxide.

Table 3 gives the results obtained with 3 per cent peroxide on the various artificial manures.

From a study of the figures in table 3 it can be seen that in general the loss of organic matter after peroxide treatment increases with the increase in the initial moisture content, and the percentage loss of dry matter during incubation. There is a corresponding increase in the apparent degree of humification with the increase in the loss of organic matter. The greater the moisture content of the manure and the greater the degree of rotting as measured by loss in dry weight, the greater is the amount of organic matter removed by the peroxide treatment. It is evident from the figures indicating the total loss

TABLE 2
Straw alone

TREATMENT	TOTAL O. M.	O.M. AFTER TREATMENT	LOSS OF O. M	TOTAL LOSS	DEGREE OF HUMIFICATION	WATER EXTRACT
	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
3 per cent H_2O_2	93.56	73.90	19.66	21.85	21.02	12.1
6 per cent H_2O_2	93.56	72.89	20.67	23.20	22.10	12.1

Artificial manure made from straw fermented with ammonium carbonate

MOISTURE CONTENT	LOSS OF DRY MATTER	TREATMENT	TOTAL O. M.	O. M. AFTER TREATMENT	LOSS OF O. M.	TOTAL LOSS	DEGREE OF HUMIFICATION	WATER EXTRACT
<i>per cent</i>	<i>per cent</i>		<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
80.3	36.5	3 per cent H_2O_2	90.12	62.94	27.18	31.9	30.16	21.14
85.0	45.8	3 per cent H_2O_2	87.26	55.64	31.62	38.2	36.00	21.23
86.0	39.2	3 per cent H_2O_2	88.90	50.60	38.30	43.41	43.08	22.23
88.6	44.4	3 per cent H_2O_2	87.50	62.90	24.60	34.52	28.12	29.30
80.3	36.5	6 per cent H_2O_2	90.12	64.73	25.39	30.01	28.17	21.14
85.0	45.8	6 per cent H_2O_2	87.26	55.11	32.15	39.22	36.85	21.23
86.0	39.2	6 per cent H_2O_2	88.90	72.30	.....	.....	.....	22.23
88.6	44.4	6 per cent H_2O_2	87.50	54.60	32.90	39.60	37.60	29.30

due to peroxide treatment and to the water extract that the loss is greater with peroxide than with water extraction. This point is also apparent in table 4 where the residue on evaporation of peroxide extract and its ash content are compared with the residue in the water extract and its ash content. In these estimations all the samples of one particular artificial manure were mixed up as evenly as possible and the extractions were then carried out as given in the foregoing. From a consideration of the figures in columns 4 and 8 the residues in water extract is always greater than in peroxide, whereas the total loss in column 3 is always greater than that in column 8. Total loss minus the residue in peroxide extract gives the matter oxidized by the reagent. The residue in the peroxide minus the ash (column 6) gives the organic matter in the peroxide extract which remains quite unaffected by the reagent, i.e., not

oxidized but only dissolved. The figure of 8.8, which is the organic matter in the resistant form in the peroxide extracts, seems to be of some significance. It is constant in five cases out of seven. This resistant form of organic matter may be compared with McLean's resistant form of nitrogen in the soil organic matter. In the first two cases when the figures are higher than 8.8 the filtrate was turbid. This turbidity may be due to the presence of a special type of

TABLE 3

MOISTURE CONTENT	LOSS OF DRY MATTER	TOTAL O. M.	O. M. AFTER TREATMENT	LOSS OF O. M.	TOTAL LOSS	DEGREE OF HUMIFICA- TION	WATER EXTRACT
<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
<i>Straw rotted with (NH₄)₂SO₄</i>							
76.54	30.1	88.98	72.70	16.28	22.90	18.30	17.94
80.70	32.5	88.45	63.8	14.65	30.68	16.53	20.50
83.30	31.6	88.52	69.5	19.02	30.51	21.50	20.84
85.25	30.7	88.86	65.21	23.65	29.75	26.61	19.84
<i>Straw rotted with NaNO₃*</i>							
84.80	52.8	78.68	35.85	42.83	57.94	54.44	44.36
86.70	52.3	77.90	33.15	44.75	62.70	57.45	62.10
<i>Straw rotted with H₂O</i>							
81.75	30.0	89.42	73.25	16.17	21.27	18.08	12.93
<i>Straw rotted with peptone</i>							
83.30	39.5	88.38	61.05	27.33	32.53	30.92	21.53
84.42	44.1	87.32	58.84	28.48	34.99	32.61	26.90
<i>Straw rotted with casein</i>							
82.9	41.8	87.60	54.10	33.50	39.33	38.24	27.20
83.6	43.0	85.70	54.70	31.00	38.33	36.20	28.90
<i>Straw rotted with urea</i>							
80.0	32.5	86.95	68.40	18.55	26.70	21.34	19.30
80.5	34.0	88.74	62.40	26.34	32.00	29.46	25.30

* This sample rotted for 45 days; other samples for 30 days only.

organic matter containing a large amount of carbohydrate material or the residues from the fungi which were seen to grow very profusely in both cases. The extraordinarily high figures in the case of sodium nitrate are no doubt due to the high degree of rotting, because the straw was rotted for over 1½ months as compared with 1 month in all the other cases. A comparison of the sodium nitrate manure with the farmyard manure, which was also well rotted, shows that the amount of organic matter after peroxide treatment and matter oxidized in each case respectively are of the same order. The quantity of

organic matter in the water extract is decidedly higher than that in the peroxide extract. Hydrogen peroxide also extracts inorganic material but the ash con-

TABLE 4

Comparison of residue on evaporation of peroxide extract and its ash content with residue in water extract and its ash content

SUBSTANCE USED FOR ROTTING THE STRAW	INITIAL O. M.	O. M. AFTER H ₂ O ₂ TREATMENT	TOTAL LOSS	RESIDUE IN H ₂ O ₂ EXTRACT	MATTER OXIDIZED	ASH IN H ₂ O ₂ EXTRACT	O. M. IN H ₂ O ₂ EXTRACT	RESIDUE IN WATER EXTRACT	ASH IN WATER EXTRACT	O. M. IN WATER EXTRACT
	1	2	3	4	5	6	7	8	9	10
	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
(NH ₄) ₂ CO ₃	88.5	59.85	35.86	20.27	15.59	4.84	15.43	31.0	20.2	10.8
NaNO ₃	78.3	27.30	68.80	27.40	41.40	14.60	12.80	57.8	25.0	32.8
(NH ₄) ₂ SO ₄	88.6	66.42	32.19	14.50	17.69	5.89	8.61	21.0	8.8	12.2
Urea.....	87.7	62.71	32.04	12.87	19.17	4.00	8.87	29.6	7.6	22.0
Peptone.....	87.8	53.20	40.30	16.35	24.00	7.80	8.55	31.8	9.2	22.6
Casein.....	86.9	56.30	36.90	15.30	21.60	6.47	8.83	27.2	7.1	20.1
Farmyard manure*.....	71.9	23.11	61.28	20.28	41.00	11.43	8.85	31.08	11.08	20.0

* Farmyard manure used alone.

TABLE 5

Extractive properties of peroxide and water

	LOSS ON 100 GM. OF THE DRY MANURE AFTER						NET LOSS DUE TO PEROXIDE TREATMENT		
	A. Water extraction			B. Peroxide ex- traction			B - A		A - B
	Total loss	Organic mat- ter loss	Ash loss	Total loss	O. M. loss	Ash loss	Total loss	O. M. loss	Ash loss
	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.
Straw.....	12.1	9.1	3.0	21.9	19.7	2.2	9.8	10.6	0.8
Straw rotted with (NH ₄) ₂ CO ₃	31.0	10.8	20.2	36.5	30.0	6.5	5.5	19.2	13.7
Straw rotted with (NH ₄) ₂ SO ₄	21.0	12.2	8.8	28.0	18.0	10.0	7.0	5.8	....
Straw rotted with NaNO ₃	57.8	32.8	25.0	61.0	43.5	17.5	3.3	10.7	7.5
Straw rotted with H ₂ O.....	13.0	7.1	4.9	21.3	16.2	5.1	8.3	9.1	....
Straw rotted with peptone.....	31.8	22.6	9.2	33.5	27.7	5.8	1.7	5.1	3.4
Straw rotted with casein.....	27.2	20.1	7.1	38.5	32.2	6.3	11.3	12.1	0.8
Straw rotted with urea.....	29.6	22.0	7.6	29.3	22.4	6.9	....	0.4	0.7
Farmyard manure.....	31.08	20.0	11.08	59.0	40.0	19.0	28.0	20.0	....

tent of the water extract is, in general, higher than that of the peroxide. The extractive properties of peroxide and water are further compared in table 5. Table 6 gives the action of peroxide on the manures extracted with alcohol.

It will be seen, in comparing the average figures for loss in organic matter, total loss, and degree of humification in the various columns in tables 1, 2, and 3 with the corresponding ones in table 6, that those in tables 1, 2, and 3 are in most cases lowered by alcoholic extraction. Alcohol removed some of the organic and inorganic matter from the manures.

The degree of humification thus appears to be a useful measure of the decomposition undergone by any one kind of plant material under different treatments. It must not be regarded as an infallible guide to the value of organic manures in general; still less as an index of the biological availability of the end products.

TABLE 6
Action of peroxide on manures extracted with alcohol

	TOTAL O. M.	O. M. AFTER H ₂ O ₂ TREATMENT	LOSS IN O. M.	TOTAL LOSS	DEGREE OF HUMIFICA- TION
	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
Straw.....	95.95	80.12	15.83	16.81	16.50
Straw rotted with (NH ₄) ₂ CO ₃	90.32	69.93	24.39	24.48	27.00
Straw rotted with (NH ₄) ₂ SO ₄ ..	87.10	72.75	14.35	22.48	16.48
Straw rotted with NaNO ₃	81.20	51.90	21.30	34.58	26.23
Straw rotted with peptone.....	89.45	49.42	40.03	44.04	44.76
Straw rotted with casein.....	87.95	65.73	22.22	27.17	25.27
Straw rotted with urea.....	92.00	62.43	29.57	33.03	32.14
Straw rotted with H ₂ O.....	92.99	93.20	..	20.85	
Farmyard manure.....	37.00	28.80	8.20	22.10	52.20

SUMMARY

The action of 3 per cent and 6 per cent hydrogen peroxide on artificial manures has been studied and it has been found that there is not much difference in the action of the two concentrations of this reagent. Peroxide attacks undecomposed straw to a certain extent.

Artificial manures can be arranged in order of rotting according to the figure for apparent degree of humification derived from loss in weight due to extraction with H₂O₂. Higher initial moisture content in a series of artificial manures results in a greater degree of humification.

In comparing the action of peroxide and water on straw and manures of different origin it has been found that (a) the effect of peroxide is more than a solvent action such as is the case with water, (b) the water extract contains more organic matter than the peroxide extract, (c) water appears to extract more inorganic substance than peroxide, (d) the amount of organic matter in the peroxide treatments is generally constant whereas that in the water shows greater variation.

In a series of artificial manures made from straw and various sources of nitrogen the degree of humification could be arranged in the following order,

proceeding from the highest to the lowest: $\{\text{NaNO}_3$ and $(\text{NH}_4)_2\text{CO}_3\}$, casein, peptone, urea, $(\text{NH}_4)_2\text{SO}_4$.

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ROTHAMSTED EXPERIMENTS ON RESIDUAL VALUES OF LEGUMINOUS CROPS¹

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THE classical experiments of Lawes and Gilbert aimed at testing the effect of manures upon the growth of each of the crops of the usual four-course rotation. The experiments on wheat, barley, and roots, and the Agdell rotation experiment, are still in being with a continuous history, but the field experiments on successive leguminous crops have been discontinued.

Lawes and Gilbert had considerable difficulty in keeping the 'continuous' leguminous plots free from weeds; first the Geescroft Field, and then part of the Hoos Field, legume plots were discarded on this account. Still later, when Sir John (then Dr.) Russell became Director, the last of the Hoos Field plots were given up for the same reason, and now only the Rothamsted House clover plot remains.

The Hoos Field leguminous plots were laid down in 1878. They consisted of three strips or series running east and west. Each strip had an area of about one acre and was differently manured: (i) with mineral manures only; (ii) with mineral manures and nitrate of soda; (iii) with mineral manures and ammonium salts or rape cake. The nitrogenous manures were in general equivalent to 86 lb. of nitrogen per acre. Each strip was further subdivided into six nearly square plots which received various mineral manures, the same for each triad of plots running north and south. These plots were numbered from 1 at the east to 6 at the west. Plot 1 of Series I (at the north-eastern corner) was used for small beds on a particular plan and is not taken into account elsewhere in this paper. The remaining seventeen plots were each divided into seven strips running north and south. Originally some fourteen different leguminous plants were sown on the area, but towards the end of last century the number of species had been reduced to seven—one on each small strip. Sowings were then uniformly made in this order from east to west on each plot: lucerne (*Medicago sativa*), beans (*Faba vulg. arvensis*) or peas (*Pisum arvense*) in alternate years, Bokhara clover (*Melilotus leucantha*), sainfoin (*Onobrychis sativa*), white Dutch clover (*Trifolium repens*), broad red clover (*T. pratense*), vetch (*Vicia sativa*). It appears that prior to 1898 sowings were broadcast.

Early in 1898 it was decided to abandon all but the five plots of Series I in the hope that better cultivation on the reduced area would help to keep down weeds. The area covered by the other two Series (about two acres) was fallowed in 1898 and sown with wheat in 1898–9 and afterwards with results that are recorded in this paper, which is concerned solely with the residual effects of the legumes of Series II and III.

The area which had been occupied by the crops of Series II and III

¹ The experiments recorded in this paper have not previously been described, the material having been allowed to accumulate pending the completion of certain field experiments on lucerne.

thus became the site of an experiment upon residual effects of leguminous crops, and, with some changes, the experiment was continued until 1922. The site was fallow in 1923. It reverted to commercial cropping of

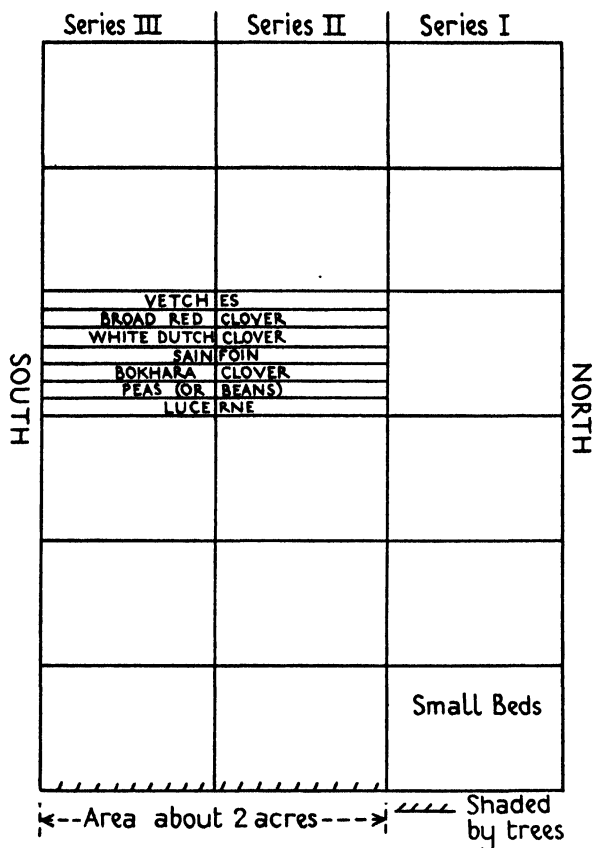


FIG. 1. Lay-out of Hoos Field leguminous land cropped with legumes, 1878-97; Series II and III cropped with wheat, 1899-1903.

barley until it was again occupied in 1930 by the long-term, modern replicated experiment known as Rotation I.

The lay-out of the experimental plots about 1898 will be seen in the diagram (Fig. 1), if it is understood that each of the small plots, except that labelled 'Small Beds', was arranged in seven strips, as shown on two plots only.

It is unnecessary to particularize yields of the leguminous crops or their manurial scheme. The manurial treatments are fully set out on page 47 of the 1901 *Memoranda* [1]. Since wheat was grown after seven various legumes each of which was manured with six different combinations of mineral manures and also with three forms of nitrogen, the experiment might have been expected to yield an impressive amount of information. As, however, the plots were not duplicated, any figures

which might have been obtained for the results of interaction of manures and residual effects might not have possessed a real value, and in any case their collection would have entailed a vast amount of work. What was done is best explained in Sir Henry Gilbert's own words in *Memoranda*, p. 51 [1], from which the following quotation is taken. The reference to the six instead of twelve plots is undoubtedly due to Sir Henry's having ignored the qualitative differences between the nitrogenous treatments, so that each adjacent pair of strips of plant was to be regarded as one.

Each of the six plots had been differently manured, and each differently manured

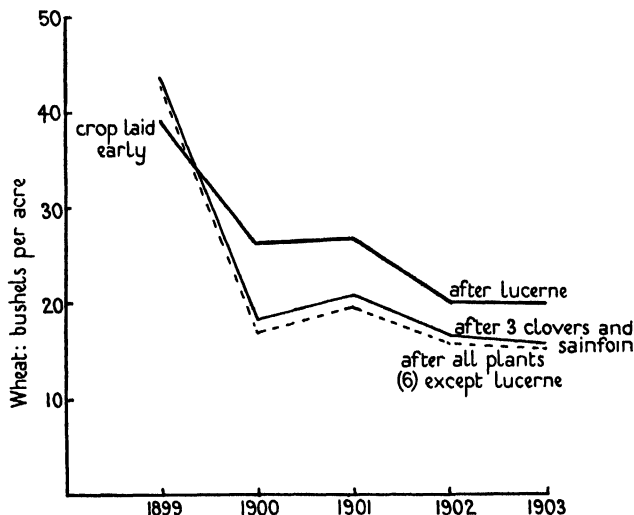


FIG. 2. Mean yields of wheat in bushels per acre after seven leguminous plants, no manure being applied to wheat.

plot had had seven different leguminous crops growing upon it. It is obvious that it would have been impracticable to harvest and thresh separately, the produce after each of the seven descriptions of plant, on each of the six differently manured plots, which would have involved the separation, and the threshing and dressing separately, of forty-two different lots. Accordingly, there were mixed together the produce after each description of leguminous plant, each grown under the six conditions as to manuring; thus reducing the number of lots to be dealt with to seven. There is obviously some disadvantage in ignoring the difference of effect of the different manures on the individual leguminous plants; but it was considered to be more important to separate the produce after the different plants, than to take that on each differently manured plot, each of which had grown seven different descriptions of leguminous plant.

No further manures being applied after 1897, Red Club wheat was sown in the autumn of 1898 after a fallow, and then a crop of wheat was taken annually until 1903 inclusive. We have thus a five-year series of records of the wheat produced on arable land without manure after seven different leguminous crops. The records are very full but the only figures reproduced here are for yield of dressed grain, of straw, and of total produce, in Tables 1 and 2. Yields of grain are shown in Fig. 2.

The condition of the wheat in the first three years after the leguminous plants was carefully noted. Though no direct record of Sir John Lawes's impressions are available, Sir Henry Gilbert has left some striking comments [1] (*Memoranda*, pp. 51 and 52):

TABLE 1. *Wheat: Yields in Bushels and in Pounds of Dressed Grain after Various Leguminous Plants, 1878-97*

After:	1899		1900		1901		1902		1903	
	bush.	lb.	bush.	lb.	bush.	lb.	bush.	lb.	bush.	lb.
Lucerne	39'25	2496	26'44	1631	27'00	1714	20'08	1198	19'98	1180
Beans or peas	42'56	2717	14'25	871	16'81	1064	14'01	853	12'97	762
Bokhara clover	43'69	2797	16'44	1008	20'13	1272	15'55	935	14'77	880
Sainfoin	45'19	2905	19'06	1169	20'88	1322	15'80	952	14'66	867
White clover	43'50	2791	19'31	1188	21'44	1348	17'88	1046	17'18	1022
Red clover	43'00	2766	19'06	1172	21'44	1342	17'73	1060	16'67	992
Vetches	39'94	2569	14'19	878	17'69	1107	13'90	841	14'02	833
Above six legumes (mean)	42'98	2757	17'05	1048	19'73	1242	15'81	948	15'04	893
The three clovers and sainfoin (mean)	43'85	2815	18'48	1134	20'98	1321	16'74	998	15'82	940

TABLE 2. *Wheat: Straw (A), and Total Produce (B), after Various Leguminous Crops, 1878-97. Weights in Pounds*

After:	1899		1900		1901		1902		1903	
	A	B	A	B	A	B	A	B	A	B
Lucerne	5499	8108	2722	4554	2312	4054	2327	3553	1837	3035
Beans or peas	5622	8430	1312	3202	1484	2571	1495	2379	1156	1926
Bokhara clover	5592	8508	1549	2582	1748	3038	1588	2542	1317	2205
Sainfoin	5611	8639	1788	2986	1796	3137	1627	2600	1380	2256
White clover	5404	8308	1707	2927	1822	3201	2011	3086	1602	2635
Red clover	5580	8505	1787	2992	1824	3185	1934	3023	1526	2528
Vetches	5051	7766	1360	2262	1591	2729	1390	2257	1261	2102
Above six legum (mean)	5477	8584	1584	2658	1711	2977	1674	2648	1374	2275
The three clovers and sainfoin (mean)	5545	8490	1658	2872	1800	3140	1790	2813	1456	2406

In the concluding years of this experiment seven plants were grown continuously (each on its own plot), viz. lucerne, peas (or beans), Bokhara clover, sainfoin, Dutch clover, red clover, vetches.

The lucerne plots (1) being shaded by adjacent trees, the produce of these plots was at first harvested separately and later omitted from the calculations, so that the later figures include only five (double) plots of lucerne, against six plots of each of the other plants.

Throughout the period of growth there was a good and even plant of wheat over the whole area, and as the season advanced there was a promise of very heavy crops; showing, however, marked distinctions according to the description of leguminous plant which had previously been grown; the luxuriance being by far the most marked on the lucerne plots, on which the wheat had a very deep-green colour, and was early laid quite flat.

It may be added that with the high condition of the land after so many years under leguminous crops, a winter and spring favourable to luxuriance, and great deficiency of rain and considerably over average temperature in the summer, early vegetative activity was followed by favourable ripening and harvest conditions. Under these circumstances, the grains were adjudged by Mr. Hewlins to be upon the whole very well grown, and characterized by great strength, the wheat after lucerne being the strongest of all, and that after the peas perhaps the weakest. The

sown with wheat. I remember how very distinct the crops showed up according to the sort of leguminous plant that had been growing previously. Several wheat crops were taken, and each crop showed the distinctive mark more or less throughout, the previous lucerne plots being very noticeable.

After these series of wheat crops, in the year 1904, the land was rearranged, being then laid out in four long strips running east to west. Three were sown with oats, and in the oats, lucerne, red clover and alsike seeds respectively and later vetches on the fourth.

The lay-out in 1904 is shown diagrammatically in Fig. 3.

The vetch strip mentioned by Grey was laid out partly on land occupied by the southern half of the old small beds and remaining leguminous strips of Series I, so that the area occupied by continuous legumes was again reduced. Results obtained upon the vetch strip are not referred to in this paper. A small part of Series II land where it adjoined Series I was included in the vetch strip. In 1904 the central area of Series II was sown to alsike clover. The southernmost part of Series III was sown to lucerne, and an intermediate portion, of equal area to the lucerne and alsike strips, was sown to red clover. Necessarily the red clover strip lay partly upon the site of Series II and partly upon the site of Series III. Lucerne, red clover and alsike were sown down in oats in May 1904. The oats were harvested together, the yields not being separately recorded.

These four strips were maintained each under an individual legume until 1911. In 1906 red clover and alsike were sown in barley, which was harvested in one lot. In 1908 no crops of red clover or alsike were obtained. Vetches were sown annually (with a fallow in 1913) on the vetch strip until 1912, after which the plot was abandoned as far as regards experiment. Yields of the four leguminous crops were recorded in all cases. They were generally satisfactory in the circumstances, so that they are not given here. This paper is concerned with the residual effects of leguminous crops and not with yields of legumes under 'continuous' cropping.

TABLE 3. *Yields of Oats and Barley after Three Legumes
Legumes 1905-11*

	1912 Oats			1913 Barley			1914 Barley		
	<i>Dressed grain bush.</i>	<i>Total straw lb.</i>	<i>Total produce lb.</i>	<i>Dressed grain bush.</i>	<i>Total straw lb.</i>	<i>Total produce lb.</i>	<i>Dressed grain bush.</i>	<i>Total straw lb.</i>	<i>Total produce lb.</i>
<i>After:</i>									
Lucerne (seven years)	50.94	3303	5153	55.17	2955	6218	32.97	1960	3853
Red clover (three years continuously)	37.18	2628	3917	38.51	2106	4339	20.26	1187	2347
Alsike clover (three years continuously)	29.13	2147	3105	35.05	2006	4037	21.94	1266	2522

This arrangement of four leguminous strips cropped to lucerne, red clover, alsike, and vetches persisted until 1912. In 1912 oats were sown without manure on the lucerne, red clover, and alsike strips, and in 1913 and 1914 barley was sown on the same plots without manure. The

resulting yields are given in Table 3, from which the superior residual effect of lucerne over both red clover and alsike is evident. Weeds had, however, been a difficulty and it is recorded that in 1911 the strip nominally devoted to alsike was largely occupied by *Phleum pratense*.

A fallow over the whole three strips was taken in 1915. The records for 1916 are incomplete; no experimental results are available so it may be presumed that if a crop was taken, it was harvested as one lot. Manures were applied in 1916 at the rate of $1\frac{1}{2}$ cwt. sulphate of ammonia per acre over the whole strip; and in addition a dressing of 3 cwt. superphosphate per acre over the eastern two-thirds.

Early in 1916 a division running north and south was made across the strips so that they were divided into a western third and an eastern two-thirds; otherwise, the three strips maintained the boundaries of 1904-5. Since 1897 they had had no added manure beyond that arising from the residues of the crops; it was only in the spring of 1916 that a beginning was made in applying artificial manures.

To the two divisions of each strip, manures were applied annually from 1916-22 inclusive at the following rates per acre, the division paths receiving no manure:

Western third

$1\frac{1}{2}$ cwt. sulphate of ammonia (actually $31\frac{1}{4}$ lb.).

Eastern two-thirds

$1\frac{1}{2}$ cwt. sulphate of ammonia and 3 cwt. superphosphate (actually $62\frac{1}{2}$ and $120\frac{1}{2}$ lb. respectively, but in 1921 and 1922, 125 lb. of superphosphate).

TABLE 4. *Hoos Field Leguminous Strips, Western Third*

Barley: Yields per acre after three leguminous crops (grown 1905-11), the barley being manured annually at the rate of 168 lb. of sulphate of ammonia per acre.

	1917		1918		1919		1920		1921		1922	
	Dressed grain bush.	Total produce lb.	Dressed grain bush.	Total produce lb.	Dressed grain bush.	Total produce lb.	Dressed grain bush.	Total produce lb.	Dressed grain bush.	Total produce lb.	Dressed grain bush.	Total produce lb.
After:												
Lucerne	28.21	3777	20.12	2340	15.78	1790	27.31	3837	14.84	2109	27.20	4133
Red clover	21.80	2899	19.39	2171	12.47	1493	16.31	2719	12.12	1750	25.16	3434
Alsike clover	22.38	3246	17.52	1930	10.64	1375	15.46	2657	11.00	1646	25.93	3375

Field notes 1920-2: The Western thirds very foul with corn thistle, &c.

TABLE 5. *Hoos Field Leguminous Strips: Eastern Two-thirds*

Barley: Yields per acre after three leguminous crops (grown 1901-11), the barley being manured annually at the rate of 168 lb. of sulphate of ammonia and 336 lb. of superphosphate per acre.

	1917		1918		1919		1920		1921		1922	
	Dressed grain bush.	Total produce lb.	Dressed grain bush.	Total produce lb.	Dressed grain bush.	Total produce lb.	Dressed grain bush.	Total produce lb.	Dressed grain bush.	Total produce lb.	Dressed grain bush.	Total produce lb.
After:												
Lucerne	32.78	3883	27.40	2778	18.44	1939	46.34	4790	37.84	4334	41.16	4786
Red clover	25.69	3023	22.85	2283	16.07	1651	33.51	3630	31.12	3683	35.44	3946
Alsike clover	27.14	3246	21.44	2185	15.42	1621	37.96	4116	28.73	3502	33.59	3684

Barley was sown annually with these manurings until 1922, when the experiment terminated. The crops were maintained distinct and the yields are shown in Tables 4 and 5. Graphs of the yields are given in Figs. 4 and 5. It will be noted that the enhanced fertility conferred by lucerne growing between 1904, when the legumes were sown down in oats, and 1911, could be easily traced until 1922. Applications of arti-

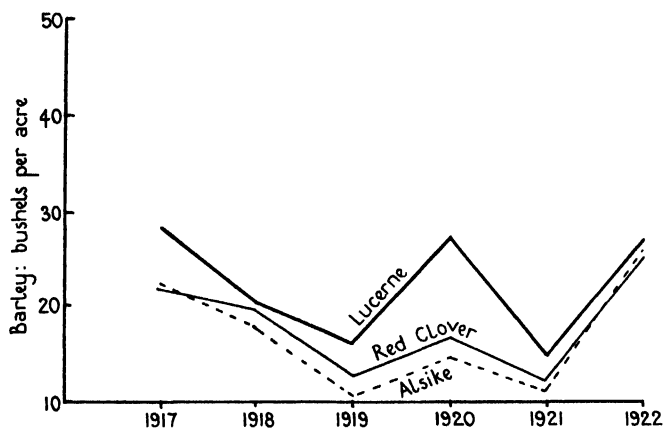


FIG. 4. Hoos Field leguminous strips: Western third. Barley yields in bushels per acre.

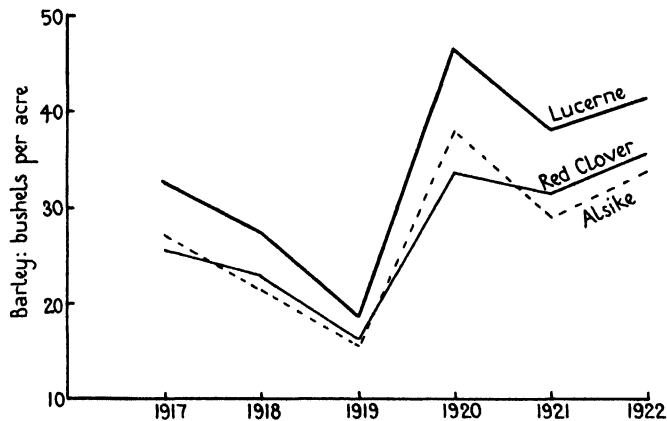


FIG. 5. Hoos Field leguminous strips: Eastern two-thirds. Barley yields in bushels per acre.

ficial manures in 1916-18 and the taking of three crops of barley in those years approximated to ordinary farming practice, and, although the taking of six successive crops of barley with manuring is not usual practice, it is noteworthy that the markedly beneficial effect of lucerne was not obscured by the artificials. To realize the residual benefits of a crop of lucerne, it is not essential to withhold artificials. Hence there seems to be no doubt that the valuable residual effect of a crop of lucerne can be fully utilized by a farmer following his usual routine. On the

other hand, with wheat as the first crop after breaking up a lucerne stand, there is a danger of the crop becoming laid even when no manure is given.

Discussion.—This long-continued experiment, begun under the aegis of Sir John Lawes and continued by two successive Directors of Rothamsted Experimental Station, has supplied information such as does not appear to have been obtained anywhere else in the world. A few experi-

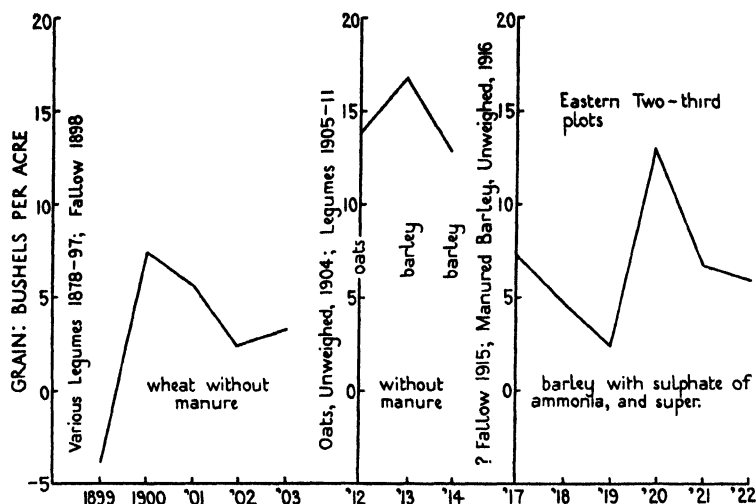


FIG. 6. Excess in bushels, in yields of grain after lucerne compared with yields after clover. ('Clover' yield subtracted from 'lucerne' yield.)

ments on the residual value of legumes have been made in the United States and elsewhere [3, 4].

There are also statements [5] made from the standpoint of a practical farmer; whilst such statements are interesting, their lack of quantitative-ness has diminished their value from a teaching standpoint.

The experiment here discussed falls into three periods:

- 1899-1903. Five successive crops of wheat without manure after each of seven leguminous plants, 1878-97.
- 1912-1914. One crop of oats and two of barley, without manure, after each of three common leguminous plants, 1905-11.
- 1917-1922. Six successive crops of barley each with two treatments with artificial fertilizers after the same leguminous plants, which had not been grown since 1911.

The graph Fig. 6 shows the *differences* in bushels (of wheat, oats, or barley for all the years 1899-1922 in which the yield of a white straw crop was recorded) between the yields of those plots which had borne lucerne and those that had borne red clover. Alsike is omitted from the comparison, but the yields of grain from the former alsike plots were in most cases lower than the 'red clover' yields.

The effects of season are marked and interesting. At no time, with the single exception of 1899, does the yield of grain after lucerne fall below the yield after any other of the six leguminous plants with which comparisons were made. This statement can be verified for the later years by a glance at the graphs, and it holds true also of the years 1899–1903. Red clover was usually, but not always, superior to alsike from the point of view of residual value. The superiority of those yields of grain obtained on the lucerne plot after 1904 might be accounted for by a superior fertility of the land formerly devoted to Series III, but it should be remembered that the records of grain yields obtained from 1899 to 1903 were obtained from six plots scattered over Series II and III. The experiments discussed thus take into account, at least in part, the influence of space, though not in the thorough manner which would satisfy a modern statistician.

To suggest, therefore, that the results are vitiated by a fertility gradient would seem to be invoking a very improbable set of coincidences. The low yields in 1899 after lucerne were, as the field notes show, due to an excessive luxuriance leading to laid crops. Subsequently, the superior residual value was quite definitely advantageous from the point of view of yield, and this advantage was maintained throughout in varying situations, years, and states of weediness. The advantage of the crop of lucerne of a preceding decade was reflected by a superiority in grain yields even with two manurial treatments involving the application of nitrogen.

The conclusion thus reached is in harmony with the few recorded results of other countries [3, 4, 5]. At Rothamsted 1 cwt. of sulphate of ammonia is required to produce a 5.5 cwt. increase of barley, so that the value of lucerne residues in 1913, after a crop of oats had been taken in 1912, can be estimated at about 3 cwt. of sulphate of ammonia. Hotter, Hermann, and Stumpf [4] estimated that a crop of lucerne in Austria was equivalent to a normal dressing of sodium nitrate applied to each of the two crops following it. Ten Eyck [5] records a Kansas farmer's experience of seeing the results on wheat of a crop of lucerne ploughed up fourteen years previously, whilst Mr. B. Weston, the present Field Superintendent at Rothamsted, asserts that the site of the lucerne strip of 1905–11 could be discerned distinctly in 1931 and faintly in 1932 amongst the crops of Rotation I.

It is noteworthy that at Rothamsted the lucerne on these experimental plots was grown without inoculation. In view of the higher protein-content of inoculated lucerne compared with uninoculated it seems probable that if the experiment were to be repeated with the knowledge now available, even more striking results would be obtained.

Summary and Abstract.—The results of cropping experiments lasting from 1899 to 1922 showed that the effect of preceding crops of legumes could be traced by increased yields of grain for several years after legumes had ceased to be grown. The residual value of lucerne was markedly superior to that of red clover and of six other legumes.

APPENDIX

As there was no control plot specifically allocated to the Rothamsted experiments on the manuring value of legume-crop residuals, results from some of the most comparable plots on fields close to the Hoos Field leguminous strips have been selected to form the tables below. Full comparison would be laborious, but the manurial value of a previous crop of lucerne is apparent even though its precise evaluation is difficult.

TABLE 6. *Wheat: Yields in bushels per acre*

Year	Hoos legumes: after lucerne without manure	Broadbalk: unmanured since 1839	Broadbalk: full minerals after 412 lb. S/A in previous year	Hoos Field: after fallow alternate years since 1875
1899	39.2	12.0	13.8	15.7
1900	26.4	12.2	11.8	11.9
1901	27.0	11.8	17.8	14.7
1902	20.1	13.3	20.2	22.4
1903	20.0	7.6	5.9	14.0
Mean	26.5	11.4	13.9	15.7

TABLE 7. *Barley: Yields in bushels per acre (Hoos Field)*

	Year	After lucerne W. third	1-A	1-AA	After lucerne E. two- thirds	2-A	2-AA
Manures lb. per acre per annum	S/A	168	206	206*	168	206	206*
	super	0	0	0	336	392	392
	1916	?	34.8	34.8	?	44.7	47.4
	1917	28.2	11.7	14.6	32.8	14.0	22.9
	1918	20.1	25.1	26.7	27.4	41.4	46.4
	1919	15.8	11.2	16.1	18.4	18.1	30.1
	1920	27.3	17.3	20.2	46.3	22.8	37.3
	1921	14.8	11.1	7.9	37.8	27.1	33.7
	1922	27.2	13.5	14.1	41.2	20.4	30.6
	Mean 1917-22	22.2	14.8	16.6	34.0	24.0	33.5

* An equivalent 275 lb. of nitrate of soda.

S/A = Sulphate of ammonia; super. = superphosphate.

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(Received January 31, 1933)

*The Concepts of Inverse Probability and Fiducial Probability
Referring to Unknown Parameters.*

By R. A. FISHER, F.R.S.

(Received November 3, 1932.)

1. *Criticism of Dr. Jeffreys's Method.*

In a paper published in these 'Proceedings'* Jeffreys puts forward a form of reasoning purporting to resolve in a particular case the primitive difficulty which besets all attempts to derive valid results of practical application from the theory of Inverse Probability.

For a normally distributed variate, x , the frequency element may be written

$$df = \frac{h}{\sqrt{\pi}} e^{-h^2(x-\mu)^2} dx,$$

where μ is the mean of the distribution, and h the precision constant. For the convenience of the majority of statisticians who prefer to use the standard deviation, σ , of the distribution, in place of the precision constant, we may note that

$$h^2 = \frac{1}{2\sigma^2},$$

and that this substitution may be made at any stage of the argument.

Jeffreys considers the question: What distribution *a priori* should be assumed for the value of h , regarding it as a variate varying from population to population of the *ensemble* of populations which might have been sampled? He sets forth a proof to the effect that this distribution must be of the form

$$df \propto \frac{1}{h} dh \propto \frac{1}{\sigma} d\sigma. \quad (1)$$

That there should be a method of evolving such a piece of information by mathematical reasoning only, without recourse to observational material, would be in all respects remarkable, especially since the same principle of reasoning should, presumably, be applicable to obtain the distribution *a priori* of other statistical parameters. The proof can, however, scarcely in any case establish all that is claimed, since there is nothing to prevent our setting up an

* 'Proc. Roy. Soc.,' A, vol. 138, p. 48 (1932).

artificially constructed series of populations having any chosen distribution of h , such as

$$df = ae^{-ah} dh,$$

in which case Jeffreys's reasoning would certainly lead to a false conclusion. Moreover, Jeffreys himself seems to feel some doubt as to the general validity of the distribution (1), for he says: "The solution must break down for very small h . . . and for large h . . ."; though he does not indicate in what way his mathematical proof fails for these parts of the range.

The principle he uses rests on the fact that, if we have three independent observations from the same population, the probability that the last of the three shall be intermediate between the first two must be exactly $1/3$. This fact is sufficiently obvious if all three observations are made afresh for each test, but we may note at once that, for any particular population, the probability will generally be larger when the first two observations are far apart than when they are near together. This is important since, as will be seen, the fallacy of Jeffreys's argument consists just in assuming that the probability shall be $1/3$, *independently of the distance apart of the first two observations*.

Since the property used is possessed by all distributions, and therefore amongst others by normal distributions having all possible values of h , it might be argued *a priori* that its existence could not possibly be used to throw light upon the frequency distribution of h . It is, in fact, only the illegitimate inference stressed above which makes such further inferences appear to be possible.

Jeffreys's argument proceeds in four steps:—(a) the probability of the first two observations having assigned values is expressed in terms of the two parameters, the mean and the precision constant, of the population; (b) introducing the probability *a priori* of the two parameters having assigned values, their posterior probability of having them is obtained; (c) the probability of the third observation having an assigned value is found and integrated over all possible values of the parameters; (d) the expression so obtained is equated to $1/3$, *without averaging it for all possible pairs of initial observations*; had this essential step been taken, the equation would have degenerated to an identity for all possible distributions *a priori*.

The argument as developed involves the assumption of a particular distribution *a priori* of the mean; it will be advantageous, therefore, in order to make clear the exact point at which a fallacy is introduced to exhibit the analysis without this assumption.

Let the population sampled have mean μ , and precision constant h , then the probability that the first two observations should lie in the ranges dx_1, dx_2 , is

$$\frac{h^2}{\pi} e^{-h^2 [(x_1 - \mu)^2 + (x_2 - \mu)^2]} dx_1 dx_2.$$

Let the larger of these observations be $u + v$ and the smaller $u - v$, then the frequency element may be re-written

$$\frac{2h^2}{\pi} e^{-2h^2 [(u - \mu)^2 + v^2]} du dv.$$

If now $f(h) dh$ is the prior probability that h lies in the range dh , the probability of assigned values for u, v and h will be

$$\frac{2h^2 f(h)}{\pi} e^{-2h^2 [(u - \mu)^2 + v^2]} du dv dh,$$

and that for assigned values of u, v, h , and the third observation, x_3 , will be

$$\frac{2h^3 f(h)}{\pi^{3/2}} e^{-2h^2 [(u - \mu)^2 + v^2] - h^2 (x_3 - \mu)^2} du dv dh dx_3.$$

Writing $x_3 = u + c$, since the magnitude of c determines whether or not the third observation lies between the others, we may now average over all values of u , by integrating with respect to that variate from $-\infty$ to ∞ .

This gives

$$\frac{2h^2 f(h)}{\pi\sqrt{3}} e^{-2h^2 v^2 - \frac{1}{3}h^2 c^2} dv dh dc, \quad (2)$$

in which μ , the mean of the population, has disappeared, showing that its value, and therefore its distribution, *a priori* is irrelevant. Equation (2) corresponds with Jeffreys's equation (3) (p. 49), save that the differential elements, dv and dc , have been retained.

For any given value of v , therefore, the probability of the third observation lying between the first two will be found by integrating (2) with respect to c and h , and evaluating the frequency with which c is less than v .

Writing

$$\alpha(x) = \frac{1}{\sqrt{\pi}} \int_{-x}^x e^{-t^2} dt,$$

the integral with respect to c from $-v$ to v is

$$\frac{2hf(h)}{\sqrt{2\pi}} \cdot \alpha(hv\sqrt{\frac{2}{3}}) e^{-2h^2 v^2} dv dh, \quad (3)$$

while the integral over all values is

$$\frac{2hf(h)}{\sqrt{2\pi}} e^{-2h^2v^2} dv dh; \quad (4)$$

it is by equating the integral of (4) with respect to h , to three times that of (3) for every possible value of v , that Jeffreys obtains a unique form for $f(h)$.

All that we really know, however, is that on the average of all values of v , the probability is exactly one-third. We should, therefore, integrate (3) and (4) with respect to v , over all values from 0 to ∞ . For (3) we have, as is also shown by Jeffreys (p. 50),

$$\frac{1}{3} f(h) dh,$$

and for (4),

$$f(h) dh,$$

so that the fact that the probability is just one-third is assured, irrespective of h , and therefore for every frequency element of that variate independently. It is merely because the substitution $f(h) = 1/h$ makes integration with respect to h equivalent to integration with respect to v , that this special distribution *a priori* satisfies Jeffreys's condition.

2. The Method of the Fiducial Distribution.

An altogether different approach may perhaps make clear why the consideration of proportional rather than absolute increments in the variables h and σ should lead to simpler mathematical consequences. If from a series of n' observations, x , drawn from a normal population with standard deviation σ , or variance σ^2 , we make an estimate of this variance, based on the sum of the squares of the deviations of the observations from their mean, in the form

$$s^2 = \frac{1}{n' - 1} S (x - \bar{x})^2,$$

then the estimate s^2 is known* to be distributed, in random samples, in a manner, which depends only on the unknown parameter σ of the sampled population, and is specified by the formula

$$df = \frac{1}{\frac{n' - 1}{2}!} \left\{ \frac{(n' - 1) s^2}{2\sigma^2} \right\}^{\frac{1}{2}(n' - 1)} e^{-\frac{(n' - 1) s^2}{2\sigma^2}} d \left\{ \frac{(n' - 1) s^2}{2\sigma^2} \right\}.$$

The distribution of the ratio s/σ is thus independent of all unknown parameters, and is calculable solely from the number of observations in the sample, or, to

* Fisher. 'Metron.', vol. 5, p. 90 (1926).

cover a more general class of cases, from the number of degrees of freedom of the residuals, from which the variance is estimated. From this distribution, which has been sufficiently tabulated, we can assert, without reference to any unknown quantities, or to their unknown probabilities *a priori*, with what frequency any particular value of the ratio s/σ will be exceeded in random samples; or, what is often more convenient, for any given probability, such as 0.99 or 0.01, what is the value of the ratio which will be exceeded with this probability. Thus for 10 degrees of freedom, such as we should have from a sample of 11 observations of a normally distributed variate, it is known that the ratio will exceed 2.3209 in 1 per cent. of cases,* and will fall short of 0.2558 in another 1 per cent. If, therefore, we designate by $s_{0.01}(\sigma)$ that value of s which, for a given σ , will be exceeded in exactly 1 per cent. of trials, we have the simple relationship

$$s_{0.01}(\sigma) = \sigma \times 2.3209,$$

and this value of s we may term the 1 per cent. value of s for the value of σ considered. If now we designate by $\sigma_{0.99}(s)$ that value of σ for which s is the 1 per cent. value, then evidently

$$\sigma_{0.99}(s) = s/2.3209,$$

and we may term this value of σ the 99 per cent. value of σ for the given value of s . Evidently where s is known this value of σ is also known. Moreover, the inequality

$$s > s_{0.01}(\sigma), \tag{5}$$

is equivalent to the inequality,

$$\sigma < \sigma_{0.99}(s), \tag{6}$$

since for any value of the probability chosen the corresponding values of s and σ increase together from 0 to ∞ .

Now we know that the inequality (5) will be satisfied in just 1 per cent. of random trials, whence we may infer that the inequality (6) will also be satisfied with the same frequency. Now this is a probability statement about the unknown parameter σ , easily translatable into an equivalent statement about the unknown parameter h , in terms of known quantities only. For example, if s is an estimate derived from 10 degrees of freedom we know that σ has a probability 0.01 of being less than $s/2.3209$, and in like manner we know its probability of falling between any other assigned limits. Probability statements of this type are logically entirely distinct from inverse probability

* Fisher, "Statistical Methods for Research Workers," Table III, 4th ed. (1932.)

statements, and remain true whatever the distribution *a priori* of σ may actually be. To distinguish them from statements of inverse probability I have called them statements of fiducial probability. This distinction is necessary since the assumption of a given frequency distribution *a priori*, though in practice always precarious, might conceivably be true, in which case we should have two possible probability statements differing numerically, and expressible in a similar verbal form, though necessarily differing in their logical content. The probabilities differ in referring to different populations; that of the fiducial probability is the population of all possible random samples, that of the inverse probability is a group of samples selected to resemble that actually observed.

It is the lack of this distinction that gives a deceptive plausibility to the frequency distribution *a priori*

$$df = d\sigma/\sigma = d(\log \sigma).$$

For this particular distribution *a priori* makes the statements of inverse and of fiducial probability numerically the same, and so allows their logical distinctness to be slurred over. It is, moreover, as Jeffreys, by his references to large and small values of h , clearly perceives, an impossible distribution *a priori*, since it gives a zero probability *a priori* for h lying between any finite limits, however far apart. In the fiducial form of statement this difficulty does not occur.

3. Summary.

(1) The argument of Jeffreys in favour of a particular frequency distribution *a priori* for the precision constant of a normally distributed variate rests on the fallacy that the probability of the last of three observations, lying between the previous two, should be one-third, *irrespective of the distance apart of the two previous observations*.

(2) The apparent simplicity of the results of assuming this particular distribution *a priori* rests on the fact that the *inverse* and the *fiducial* probability statements about the unknown parameter are thereby made to coincide, though logically they are entirely distinct. This particular distribution *a priori* is, however, not only hypothetical but unacceptable as such, since it implies that all ranges of values of the parameter covering finite ratios, however great, are infinitely improbable.

MISCELLANEA.

CONTENTS.

	PAGE
Application of the Method of Maximum Likelihood to the Improvement of Curves fitted by the Method of Moments. By R. S. KOSHAL, M.Sc.	303
A Quantity Index-Number. By E. C. RHODES, D.Sc.	314

APPLICATION OF THE METHOD OF MAXIMUM LIKELIHOOD TO THE IMPROVEMENT OF CURVES FITTED BY THE METHOD OF MOMENTS.

By R. S. KOSHAL, M.Sc.

(Statistical Department, Rothamsted Experimental Station,
Harpenden).*Introduction.*

THE method of moments was regarded as efficient in fitting Pearsonian Curves, prior to 1921, when it was shown (1) by Fisher, that its efficiency is restricted to a small region for which β_2 lies between the limits 2.65 and 3.42; and for which β_1 does not exceed 0.1. Later (3) the same writer pointed out that the goodness of fit test will not be accurate if the method of fitting employed is inadequate; that is, if the statistics used in the estimation of parameters are inconsistent or inefficient. A statistic satisfying the criterion of efficiency can be found by the method of maximum likelihood as shown by Fisher in his paper, "The Mathematical Foundations of Theoretical Statistics" (1). This method may briefly be stated as follows:—

If in a frequency distribution obtained from a sample taken at random from a population specified by a parameter θ (or set of parameters), n_s represents the observed frequency in the class s and p_s is the probability of its occurrence in the same class (p_s being a function of the parameter θ), then an efficient estimate of the parameter θ can be obtained by maximizing the quantity

$$L = S(n_s \log p_s)$$

for variations of θ .

On account of mathematical difficulties it is not always possible to obtain an algebraic solution of maximum likelihood equations. In these circumstances it was later (4) shown by Fisher, that starting from an inefficient statistic it is possible to obtain by a single process of approximation an efficient statistic. This approximate method

of obtaining an efficient statistic from an inefficient statistic is used in the following pages to improve the statistics obtained by the method of moments. The method will be illustrated by its application to a coarsely-grouped frequency distribution belonging to Pearson's Type I.

Although the general theory, and the principle of its practical application, has thus been available for many years, the teaching of the improved methods, and even of the very evident need for improvement, has lagged behind, principally, perhaps, for lack of simple published examples, exhibiting the practical handling of the improved method. The example chosen is one in which the method of moments is not especially inefficient, though its failure on the question of goodness of fit is sufficiently evident; its chief interest lies in the treatment of the two practical difficulties caused by (a) grouped data, and (b) the use of a type of curves in which the equations of maximum likelihood involve integrals of a troublesome form. It is shown that neither type of difficulty need stand in the way of obtaining an efficiently fitted curve.

The Method of Approximate Solution.

Let us consider the simple case in which p_i is a function of two parameters θ_1 and θ_2 . Let T_1 and T_2 indicate the moment solution, and T_1' , T_2' represent the efficient statistics obtained by the method of maximum likelihood to a first approximation. The corrections $T_1' - T_1$ and $T_2' - T_2$ can be calculated from the symmetrical equations:

$$\left. \begin{aligned} (T_1' - T_1) \frac{\partial^2 L}{\partial \theta_1^2} + (T_2' - T_2) \frac{\partial^2 L}{\partial \theta_1 \partial \theta_2} &= -A_1 \\ (T_1' - T_1) \frac{\partial^2 L}{\partial \theta_1 \partial \theta_2} + (T_2' - T_2) \frac{\partial^2 L}{\partial \theta_2^2} &= -A_2 \end{aligned} \right\}$$

The values A_1 and A_2 are the discrepancies from zero of $\frac{\partial L}{\partial \theta_1}$ and $\frac{\partial L}{\partial \theta_2}$ when T_1 , T_2 are substituted for θ_1 and θ_2 . It may also be noted that in the evaluation of the differential coefficients in the left-hand side of the equations, T_1 and T_2 are substituted for θ_1 and θ_2 .

In certain cases, however, it is not possible or convenient to calculate the values of $\frac{\partial L}{\partial \theta_1}$, $\frac{\partial L}{\partial \theta_2}$, $\frac{\partial^2 L}{\partial \theta_1^2}$, $\frac{\partial^2 L}{\partial \theta_2^2}$ and $\frac{\partial^2 L}{\partial \theta_1 \partial \theta_2}$ numerically; whereas L can be calculated directly from the equation:

$$L = S(n_i \log p_i).$$

It will be shown that an adequate set of such values of L may be used to complete the necessary approximation.

In this method, first the value of L is calculated by using the values of p_s obtained from the moment estimate of θ_1 and θ_2 . Let us write this value of L as L_{00} . Then θ_2 is kept constant and θ_1 is varied by giving it suitable small and equal increments, and from the two sets of values of p_s thus obtained, two new values of L are calculated which are on either side of the value of L for the maximum likelihood solution. Let these values be designated L_{10} and L_{20} ; where L_{10} indicates that θ_1 is given one small increment, while L_{20} shows that two small increments are given to θ_1 and that in both the cases θ_2 is not changed. Similarly by keeping θ_1 constant and giving small increments to θ_2 , two values of L indicated by L_{01} and L_{02} are obtained. Finally, L_{11} is calculated from the values of p_s obtained by giving one increment each, simultaneously to θ_1 and θ_2 .

If the true maximum of L is found by giving corrections x and y to our first estimates, x and y being measured in terms of our chosen increments as units, then the value of the likelihood obtained from any trial values using ξ and η increments respectively must be a maximum when $\xi = x$ and $\eta = y$. We may consequently express the value of L in terms of ξ and η in the neighbourhood of the maximum by the approximate quadratic expression :

$$L = c - a(x - \xi)^2 - 2h(x - \xi)(y - \eta) - b(y - \eta)^2 \quad (i)$$

where ξ and η take the values 0, 1, 2 in the trial cases evaluated.

For the moment solution, L_{00} , $\xi = 0$ and $\eta = 0$, while for the other trial values :

L_{10}	$\xi = 1$	$\eta = 0$
L_{20}	$\xi = 2$	$\eta = 0$
L_{01}	$\xi = 0$	$\eta = 1$
L_{02}	$\xi = 0$	$\eta = 2$
L_{11}	$\xi = 1$	$\eta = 1$

Substituting these values of ξ and η in equation (i) we obtain the simultaneous equations :

$$\left. \begin{aligned} L_{10} - L_{00} &= a(2x - 1) + 2hy \\ L_{01} - L_{00} &= 2hx + b(2y - 1) \end{aligned} \right\} \quad (ii)$$

The solution of equation (ii) will give the values of x and y if the coefficients a , b and h are known. The values of these coefficients can be obtained from the knowledge of the values L_{00} , L_{10} , L_{20} , L_{01} , L_{02} and L_{11} already calculated by the use of the following equations :

$$L_{20} - 2L_{10} + L_{00} = -2a \quad (iii)$$

$$L_{02} - 2L_{01} + L_{00} = -2b \quad (iv)$$

$$L_{11} + L_{00} - L_{01} - L_{10} = -2h \quad (v)$$

In order to estimate the values of the four parameters α , β , μ_1 and μ_2 by the method of maximum likelihood it is necessary to calculate fourteen new and different values of L in addition to one given by the moment solution. The number 15 is obtained by putting $s = 4$ in the general formula $\frac{1}{2}(s+1)(s+2)$.

It will be shown that by suitably choosing the interval (*i.e.* increments to be given to α , β , μ_1 and μ_2 separately) the arithmetical labour of calculation of these different values of L can be reduced to a minimum. The method will be clear from its application to the frequency distribution of fibre-strength of 1,000 fibres of an Indian cotton, to which Pearson's Type I curve was fitted (6) by the method of moments.

The estimates of the four parameters for this distribution, as obtained by the method of moments, are :

$$\begin{aligned}\alpha &= 0.3298 \\ \beta &= 16.67375 \\ \mu_1 &= 0.702432 \\ \mu_2 &= 4.948333\end{aligned}$$

Starting from this inefficient moment solution it is required to obtain the maximum likelihood solution of these parameters.

The calculations necessary for evaluating each L may be divided into three steps: (1) the calculation of mid-ordinates, (2) calculation of values of p_s from the mid-ordinates and (3) the calculation of L from the equation $L = S(n_s \log p_s)$.

(i) The calculation of mid-ordinates.

The mid-ordinates were calculated from the equation :

$$\log y = \log (\beta - \alpha)^{-\overline{\mu_1 + \mu_2 + 1}} + \log \frac{\overline{\mu_1 + \mu_2 + 1}!}{\mu_1! \mu_2!} + \mu_1 \log (x - \alpha) + \mu_2 \log (\beta - x).$$

The process of obtaining the values of $\log y$ for the fourteen values of L in addition to that of L_{0000} is illustrated in Table I, in which any new value to be calculated in each case is indicated by a \times .

L_{0000} indicates the moment solution, L_{1000} shows that one increment is given to α , while β , μ_1 and μ_2 are unaltered; L_{0100} shows that one increment is given to β keeping α , μ_1 and μ_2 unchanged. Similarly, L_{1100} indicates that both α and β are given one increment each (these increments correspond to those given in the case of L_{1000} and L_{0100}), while μ_1 and μ_2 are left unaltered.

The only laborious calculations in the evaluation of $\log y_0$ are the calculation of log gamma functions, and it will be seen from the table that with the exception of $\log \Gamma(\mu_1 + \mu_2 + 2)$ for L_{0011} , these need not be calculated for the last six values of L , and for those values of L in which μ_1 or μ_2 is not changed.

TABLE I.
Calculation of $\log y$ for different L's.

L.	$\log y_0$.						$\mu_1 \log (x - \alpha)$.		$\mu_2 \log (\beta - x)$.	
	$\mu_1 + 1.$	$\log (\beta - \alpha)$.	$\frac{(\mu_1 + 1)}{\mu_2 \times \log (\beta - \alpha)}$.	$\log \Gamma(\mu_1 + 2)$.	$\log \Gamma(\mu_1 + 1)$.	$\log \Gamma(\mu_2 + 1)$.	Column of $\log (x - \alpha)$.	Column of $\mu_1 \log (x - \alpha)$.	Column of $\log (\beta - x)$.	Column of $\mu_2 \log (\beta - x)$.
L ₀₀₀₀	×	×	×	×	×	×	×	×	×	×
L ₁₀₀₀		×	×				×	×		
L ₂₀₀₀		×	×				×	×		
*L ₀₁₀₀		×	×							
*L ₀₂₀₀		×	×							
†L ₀₀₁₀	×		×	×	×					
†L ₀₀₂₀	×		×	×	×					
†L ₀₀₀₁	×		×	×		×				
†L ₀₀₀₂	×		×	×		×				
L ₁₁₀₀		×	×							
L ₁₀₁₀			×							
L ₁₀₀₁			×							
L ₀₁₁₀			×							
L ₀₁₀₁			×							
L ₀₀₁₁	×		×	×						

* The values of $\mu_2 \log (\beta - x)$ were obtained by simply shifting the frequencies, since the interval chosen was equal to the class interval.

† Since the interval in μ_1 was 0.1, the values for $\mu_1 \log (x - \alpha)$ were obtained by adding $\frac{1}{7} \log (x - \alpha)$ to the value for L₀₀₀₀.

‡ Similarly, the interval for μ_2 being 0.25, values of $\mu_2 \log (\beta - x)$ were obtained by adding $\frac{1}{4} \log (\beta - x)$ to the values for L₀₀₀₀.

The only calculation involving the frequencies is to build up a column of figures for $\mu_1 \log (x - \alpha)$ and $\mu_2 \log (\beta - x)$ for each class interval, which when added to $\log y_0$ provide the column for $\log y$. In the case of L₀₀₀₀ these columns are given by the moment solution, and of these the column $\mu_1 \log (x - \alpha)$ can be used in those cases of L where μ_1 and α are unchanged, i.e. for L₀₁₀₀, L₀₂₀₀, L₀₀₀₁, L₀₁₀₁ and L₀₀₀₂, while the column $\mu_2 \log (\beta - x)$ can be used where μ_2 and β are unaltered, i.e. for L₁₀₀₀, L₂₀₀₀, L₀₀₁₀, L₁₀₁₀ and L₀₀₂₀. For the remaining four values of L, the columns of $\log y$ can be obtained by combining the column of $\mu_1 \log (x - \alpha)$ of one L with the $\mu_2 \log (\beta - x)$ column of another suitable L; thus for L₁₀₀₁ the column $\mu_1 \log (x - \alpha)$ for L₁₀₀₀ and $\mu_2 \log (\beta - x)$ for L₀₀₀₁ can be used. Similarly in the case of L₀₀₁₁, the columns for L₀₀₁₀ and L₀₀₀₁ can be utilized. In some cases, however, as in the present example, by suitably choosing the interval (increments to be given to β , μ_1 and μ_2) it is not necessary to calculate the columns of $\mu_1 \log (x - \alpha)$ for L₀₀₁₀, L₀₀₂₀; and $\mu_2 \log (\beta - x)$ for L₀₁₀₀, L₀₂₀₀, L₀₀₀₁, L₀₀₀₂. It will be seen from the table that out of twenty-eight columns only two have been calculated (for L₁₀₀₀ and L₂₀₀₀), and the rest have been obtained from the columns of $\mu_1 \log (x - \alpha)$

and $\mu_2 \log (\beta - x)$ provided by the moment solution. Thus columns of $\log y$ can be built up for all the values of L in a very short time, especially if an adding machine is available.

(ii) Calculation of values of p_s from the mid-ordinates.

For this purpose the area for each class interval was calculated from mid-ordinates by a simple quadrature formula :

$$\int_{-\frac{1}{4}}^{\frac{1}{4}} y_x dx = y_0 - \frac{1}{24} \delta^2 y_0,$$

which was found to be adequate for all the frequency classes, except the first, for which the area was calculated by subtraction from the total frequency unity.

(iii) The logarithm of the values of p_s found in (ii) are multiplied by the corresponding observed frequency n_s in that class interval and the sum of these products gives the required L . If a calculating machine is available this sum can be obtained in a very short time without recording separately the individual products $n_s \log p_s$ for each class.

The different values of L obtained by this process are :

(i) L_{0000} (moment solution)	=	- 947.134306
(ii) α varying, β, μ_1, μ_2 constant.		
$\alpha = 0.39480$	$L_{1000} =$	- 946.559780
$\alpha = 0.45980$	$L_{2000} =$	- 946.660108
(iii) β varying, α, μ_1, μ_2 constant.		
$\beta = 15.67375$	$L_{0-100} =$	- 951.186113
$\beta = 17.67375$	$L_{0100} =$	- 947.994989
(iv) μ_1 varying, α, β, μ_2 constant.		
$\mu_1 = 0.602432$	$L_{00-10} =$	- 949.988346
$\mu_1 = 0.802432$	$L_{0010} =$	- 947.203417
(v) μ_2 varying, α, β, μ_1 constant.		
$\mu_2 = 4.698333$	$L_{000-1} =$	- 946.866042
$\mu_2 = 4.448333$	$L_{000 2} =$	- 948.368457
(vi) α, β varying, μ_1, μ_2 constant.		
$\alpha = 0.39480$ $\beta = 17.67375$	$L_{1100} =$	- 948.021911
(vii) α, μ_1 varying, β, μ_2 constant.		
$\alpha = 0.39480$ $\mu_1 = 0.802432$	$L_{1010} =$	- 947.507773
(viii) α, μ_2 varying, μ_1, β constant.		
$\alpha = 0.39480$ $\mu_2 = 4.698333$	$L_{100-1} =$	- 946.816972
(ix) β, μ_1 varying, μ_2, α constant.		
$\beta = 17.67375$ $\mu_1 = 0.802432$	$L_{0110} =$	- 950.398053
(x) β, μ_2 varying, μ_1, α constant.		
$\beta = 17.67375$ $\mu_2 = 4.698333$	$L_{010-1} =$	- 949.875851
(xi) μ_1, μ_2 varying, α, β constant.		
$\mu_1 = 0.802432$ $\mu_2 = 4.698333$	$L_{001-1} =$	- 948.480784

It may be noted that both the trial values of α (0.39480, 0.45980) are on the positive side of the value of α (0.3298) for the moment solution. The reason for this is that for the moment value $L = -947.134306$, and for $\alpha = 0.39480$, $L = -946.559780$, a *higher* value, consequently to get a lower value of L (*i.e.* after it has passed the maximum) α should be given another increment in the *same* direction. In fact $\alpha = 0.45980$ has given a lower value of $L = -946.660108$. Hence these values of α are on either side of the maximum likelihood solution. For similar reasons the two values of μ_2 are on the negative side of the moment value. This alteration in no way changes the scheme of calculation outlined in Table I, if the appropriate increments (positive or negative) are substituted.

These values of L provide four simultaneous equations for the required increments x , y , z and w to be added to the moment-estimates of α , β , μ_1 and μ_2 in the form :

$$\begin{aligned} 2ax + 2ey + 2fz + 2gw &= L_{1000} - L_{0000} + a = 0.911953 \\ 2ex + 2by + 2hz + 2iw &= L_{0100} - L_{0000} + b = 1.595562 \\ 2fx + 2hy + 2cz + 2jw &= L_{0010} - L_{0000} + c = 1.392465 \\ 2gx + 2iy + 2jz + 2dw &= L_{0000} - L_{000-1} - d = -1.153604 \end{aligned}$$

where the values of the ten coefficients a , b , c , d , e , f , g , h , i and j are all obtained from the values of L by the following equations :

$$\begin{aligned} \text{I. } L_{2000} - 2L_{1000} + L_{0000} &= -2a & a &= 0.337427 \\ \text{II. } L_{0-100} - 2L_{0000} + L_{0100} &= -2b & b &= 2.456245 \\ \text{III. } L_{00-10} - 2L_{0000} + L_{0010} &= -2c & c &= 1.462526 \\ \text{IV. } L_{0002} - 2L_{0001} + L_{0000} &= -2d & d &= 0.8853395 \\ \text{V. } L_{1100} + L_{0000} - L_{0100} - L_{1000} &= -2e & e &= 0.300724 \\ \text{VI. } L_{1010} + L_{0000} - L_{0010} - L_{1000} &= -2f & f &= 0.439441 \\ \text{VII. } L_{100-1} + L_{0000} - L_{000-1} - L_{1000} &= +2g & g &= -0.262728 \\ \text{VIII. } L_{0110} + L_{0000} - L_{0010} - L_{0100} &= -2h & h &= 1.1669765 \\ \text{IX. } L_{010-1} + L_{0000} - L_{000-1} - L_{0100} &= +2i & i &= -1.074563 \\ \text{X. } L_{001-1} + L_{0000} - L_{000-1} - L_{0010} &= +2j & j &= -0.7728155 \end{aligned}$$

The values of x , y , z and w obtained from these four symmetrical equations are multiplied by the appropriate units in order to get the "corrections."

	Units.	
$x = +1.19635$	0.065	$x' = +0.07776$
$y = +0.12573$	1.00	$y' = +0.12573$
$z = -0.111025$	0.10	$z' = -0.011103$
$w = -0.24078$	0.25	$w' = -0.060195$

The estimates of the parameters α , β , μ_1 and μ_2 by the two methods are :

Parameter.	Method of Moments.	Method of Maximum likelihood (first approximation)
α	0.32980	0.40756
β	16.67375	16.79948
μ_1	0.702432	0.691329
μ_2	4.948333	4.888138

The theoretical frequencies obtained by using these two sets of estimates in the Type I equation are given in Table II, where for the sake of comparison χ^2 is also evaluated.

TABLE II.

Theoretical Frequency Distribution.

(Type I obtained by the method of moments and method of maximum likelihood.)

Strength-class. Grams.	Observed Frequency. m	Theoretical Frequency.		Calculation of χ^2 .			
		Method of Moments. m'	Method of Maximum Likelihood. m''	Method of Moments.		Method of Maximum Likelihood.	
				$m - m'$	$\frac{(m - m')^2}{m'}$	$m - m''$	$\frac{(m - m'')^2}{m''}$
0.0 - 0.95	38	49.04	42.06	-11.04	2.4853	-4.06	0.3880
0.95- 1.95	165	156.52	154.94	8.48	0.4594	10.06	0.6531
1.95- 2.95	188	179.38	181.50	8.62	0.4142	6.50	0.2328
2.95- 3.95	159	166.19	168.80	-7.19	0.3111	-9.80	0.5689
3.95- 4.95	137	138.89	140.77	-1.89	0.0254	-3.77	0.1009
4.95- 5.95	114	107.08	108.76	6.92	0.4472	5.24	0.2524
5.95- 6.95	81	77.01	78.65	3.99	0.2067	2.35	0.0702
6.95- 7.95	48	53.08	53.32	-5.08	0.4861	-5.32	0.5371
7.95- 8.95	29	34.48	33.68	-5.48	0.8709	-4.68	0.6502
8.95- 9.95	19	19.85	19.66	-0.85	0.0364	-0.66	0.0222
9.95-10.95	15	10.61	10.40	4.39	1.8164	4.60	2.0334
above 10.95	7	7.87	7.46	-0.87	0.0961	-0.46	0.0283
		$\chi^2_P \} n = 7$ L		7.6552 (0.371) -947.134306		5.5375 (0.596) -946.494469	

A number of interesting points which emerge from the study of this table are given below :

(1) The likelihood of the set of values obtained by the first approximation method is higher than any of the trial sets.

(2) From the columns giving the contribution to χ^2 of individual classes it will be noticed that the value 2.4853 for the first class interval has been reduced to 0.3880, thus improving the fit of the theoretical curve.

(3) From the values of χ^2 , P it can be concluded that the maximum likelihood solution has given a better fit also as judged by the χ^2 test than that obtained by the method of moments.

Of the value of χ^2 obtained from the method of moments; about 2.1, or over a quarter of its value, is ascribable to inefficient fitting.

It should be noted that as shown (2) by Fisher in the calculation of P , n should be equal to the number of degrees of freedom. The values of P have been calculated from the table of χ^2 given (5) in *Statistical Methods for Research Workers*, using $n = 7$.

(4) Evidently if for any reason higher precision were required, the process could be repeated with trial values nearer to the maximum likelihood solution.

Summary.

A method is given for the improvement of inefficient statistics obtained by the method of moments. It consists in the evaluation of a number of L 's directly from the equation $L = S(n, \log p_s)$. For the estimation of S parameters it requires the calculation of $\frac{1}{2}(S+1)(S+2)$ values of L . These values of L provide simultaneous equations from which the corrections to be added to the moment estimates of the parameters can be calculated. The method is illustrated by its application to a coarsely-grouped skew distribution to which Pearson's Type I was fitted by the method of moments. It is shown that the calculation of additional fourteen values of L is not laborious, as most of the material for this calculation is provided by the moment solution.

I am highly indebted to Dr. R. A. Fisher, Sc.D., F.R.S., for suggesting to me this problem, and for the very valuable advice which he has given at every important step. My thanks are also due to the Indian Central Cotton Committee for providing facilities to work at the Rothamsted Experimental Station.

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ON THE VALIDITY OF FISHER'S z TEST WHEN APPLIED TO AN ACTUAL EXAMPLE OF NON-NORMAL DATA.

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(With Five Text-figures.)

INTRODUCTION.

THE consideration of errors of experiments involving small samples dates from the work of 'Student' (13) nearly a quarter of a century ago. Starting from experimental considerations, he found a curve representing the frequency distribution of values of the means of small samples which was approximately appropriate to populations that were not strictly normal. On this basis he proposed a test of significance of means, known as 'Student's' z , which has become very widely used in biological and agricultural experiments.

Interest in the statistics of small samples was subsequently enhanced by the development by Fisher (4) of the t and z tests, the former being an analogue of 'Student's' z , and the latter a measure of the significance of variance and intraclass correlation. Since the publication of probability tables for Fisher's z , the method known as the analysis of variance has enjoyed widespread use, and the literature of experimental data to which it has been applied increases in volume.

There has recently become evident an epidemic of doubt as to whether these tests are suitable for application to non-normally distributed material. The difficulty has been felt both by the statistician who approaches the problem from a theoretical standpoint, and by the biological and agricultural worker who uses the methods as a matter of analytical routine. For example, the latter is familiar with the phenomenon that similarly treated plots of low fertility sometimes show greater variation than plots of high fertility; consequently in experiments involving plots producing yields that are fairly wide in their range, the fear is latent that the pooling of contributions to residual variance from diverse sources, and the use of the z test, may give misleading results. Maskell (7) regards this instance as being of very infrequent occurrence in field trials. Nevertheless there is some justification for regarding the

distribution of yields from field trials and other similar cropping data as being restricted by what may be termed a "ceiling," which imparts a not very clearly defined degree of abnormality to the population.

The doubts of the statistician have been embodied in a concrete form in a number of papers. Shewhart and Winters⁽¹²⁾ took samples from normal, rectangular and right-triangular distributions and tested the validity of 'Student's' z distribution, finding satisfactory agreement only in the case of the normal population. E. S. Pearson⁽⁸⁾ similarly tested the goodness of fit of the 'Student' distribution for samples drawn from a series of non-normal Pearsonian distributions. The results were on the whole inconclusive. An anonymous reviewer⁽¹⁾ of Fisher's *Statistical Methods* stated that it was "almost certain" that Fisher's z was less applicable to non-normal material than 'Student's' z . In reply 'Student'⁽¹⁴⁾ reaffirmed his belief that his z distribution was not markedly deficient even in such cases, and supposed that small modifications of the published tables might meet the objections. Fisher⁽⁵⁾ later pointed out that the task of constructing new tables for every possible variation in distribution was an impossible one, but averred that he had never known difficulty to arise in biological work from imperfect normality of variation, notwithstanding that examination for such difficulties had often been made. E. S. Pearson⁽⁹⁾ has asked over what range of non-normality the t and z tests cease to be valid, and in a subsequent paper⁽¹⁰⁾, dealing with the application of Fisher's z to Pearsonian systems, concludes that the analysis of variance is applicable over a fairly wide range of non-normality, provided that the degrees of freedom apportioned to residual variance are not too small. Rider⁽¹¹⁾ has added the U-shaped universe to those already mentioned, and Baker⁽²⁾ has in a similar fashion treated theoretical non-homogeneous populations.

From the point of view of the investigator who is using statistics as a tool, the usefulness of the foregoing discussions is minimised by the fact that the theoretical distributions from which the samples were drawn bear no relationship to those he is likely to encounter; moreover in most of these researches the sample number used has not exceeded five. To be of use to the experimenter the following conditions must be observed:

- (1) Samples must be taken from one or more actual distributions.
- (2) The experimental procedure must correspond with what would be used on actual investigational data.
- (3) The departure of the distribution of the statistics tested from expectation must itself be tested for significance, and the sampling must

be sufficiently extensive to give reliable evidence of the distribution in the neighbourhood of the 5 and 1 per cent. probability points, since these are the regions of paramount interest in the interpretation of results.

The following investigation aims at the fulfilment of these requirements.

EXPERIMENTAL DATA.

In a study of qualitative inheritance, Fisher, Immer and Tedin (6) obtained evidence of two types of bias in their results. In addition to a dominance bias due to the segregation in successive generations of dominant characteristics favouring larger biometrical values, there appeared to be what they termed a metrical bias independent of genetical considerations. Their data consisted of height measurements of barley randomly selected from plots receiving various nitrogenous fertilisers. The metrical bias showed itself in the form of a negative skewness of

1	2	3	4	5	6	7	8
65	69½	64½	45½	42½	33	62	49
42	65	37	47½	54½	55½	66	66
26	71	74½	51	42	36½	31½	47
39½	53½	83	60	68½	41	61	50
72	66½	61	37½	49½	39	50½	66½
51½	45	64½	45	63	13	54	66
74½	21½	40	51	75	23	61	54
62½	63	63	70	57½	16½	48½	77
.....
40	58	60	68½	73	35½	59	66
57½	35	64½	78	47	23	59	68½
61	55	53	67½	75½	25½	73½	65
63	46½	60½	77	69	29	58	53½
45	51	64	84½	25½	20	75½	53½
48½	58½	23	77	37½	51	68½	68½
68	61	43	72	46	58½	63	50
46	54½	21	50	63	21	70	48½
.....
68	65½	58	72½	63	40½	60	64
21	64	52	63½	29½	62	68	34
46½	67	71	59	49	55½	64	63
42	60	58½	73	52	55	52	50
68	65	25½	68	67	42	56	76½
68	53	66	47½	60	55½	52½	46
26½	57½	68	73	63½	33½	53½	36½
43	47	64½	21	31	48	64	53½
.....
44	62	52	77½	76	61½	73	50
40½	53	60	42	37½	36½	76	26
26	78	70	61	37	49	63	65
56	69	67½	55	42½	44½	54	62½
69½	65½	50	61	44½	63½	70	69
77	64	61½	56	66½	65½	70½	72½
56	52	45½	74	60	50	62½	78½
68	61	63	26	54	55½	63	58

Fig. 1. Shoot height measurements in cm. on eight blocks of Yeoman II wheat.

the distribution, a ceiling effect tending to give smaller errors at the higher end of the height range.

The Rothamsted plots in the Ministry of Agriculture and Fisheries' Agricultural Meteorological Scheme provided us with eight blocks of two varieties of wheat on which to make tests for metrical bias. Wheat was chosen as providing another crop in which to look for abnormality, and of the two varieties Yeoman II was chosen because the symptoms of non-normality were the more developed.

The sampling of the blocks was carried out by means of Clapham's dissected metre row(3); the sub-unit was a quarter metre and in each block there were four placings of the rod. The rows upon which the placings were made were selected entirely at random, after discarding border rows, but the position within the rows was partially controlled in order to make use of the whole length of the block. Plants at both ends of the $\frac{1}{4}$ metre sub-unit were measured, thus giving 32 measurements per block, and 256 for the whole experiment. Fig. 1 gives the harvest shoot height measurements from the dissected metre samples, disposed in their respective blocks; shoot height is defined as the height from ground level to the auricle of the last expanded leaf.

That the data show distinct differences between the blocks is brought out clearly by the analysis of variance in Table I.

Table I. *Analysis of variance of shoot height: Mean 55.23 cm.*

	Sums of squares	of freedom	Mean square
Between blocks	8422.80	7	1203.26
Within blocks	46446.65	248	187.28
Total	54869.45	255	—
Blocks <i>v</i> within blocks	$z \begin{cases} \text{Calculated: } 0.9300 \\ P=0.01: 0.4822 \end{cases}$		

Fig. 2 is a distribution histogram of the data showing the frequency of positive and negative deviations from the individual block means; a decided negative skewness is manifest.

It is interesting to find the values of the actual third degree statistics which were employed by Fisher, Immer and Tedin(6). The two statistics used were the covariance of the mean and the variance (cov. k_1 , k_2), and k_3 , for which the following relationships hold (Fisher(4)):

$$k_3 = \frac{n}{(n-1)(n-2)} S_3,$$

$$S_3 = s_3 - \frac{3}{n} s_2 s_1 + \frac{2}{n^2} s_1^3,$$

$$s_1 = S(x); \quad s_2 = S(x^2); \quad s_3 = S(x^3),$$

n = number of observations.

The evidences for negative skewness in the Fisher, Immer and Tedin data were a negative covariance, which was not, however, significant owing to the crudity of the test, and a negatively significant k_3 statistic.

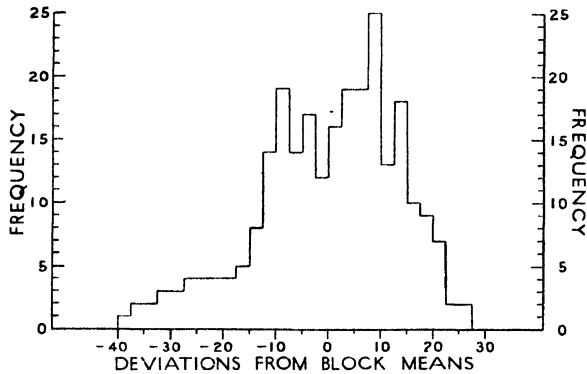


Fig. 2. Distribution histogram of deviations from block means.

In the present instance the block has been taken as the unit. This enabled a covariance with seven degrees of freedom only to be calculated, and eight values of k_3 . Table II gives the data for the eight blocks from which the covariance was derived, together with s_1 and s_2 , used in the subsequent calculation of k_3 .

Table II. *First and second degree statistics for the eight blocks.*

Block	s_1	s_1/s_2	s_2	$s_2 - \frac{1}{n} s_1^2$	Mean square
1	1682.0	52.5625	95929.50	7519.375	242.560
2	1858.0	58.0625	111661.50	3781.375	121.980
3	1809.5	56.5469	108966.75	6645.080	214.357
4	1912.0	59.7500	121748.50	7506.500	242.145
5	1722.0	53.8125	99026.50	6361.375	205.206
6	1339.0	41.8438	63077.00	7048.219	227.362
7	1963.0	61.3438	123052.50	2634.719	84.991
8	1854.0	57.9375	112366.00	4949.875	159.673
	14139.5		835828.25	46446.518	

Table III. *Values of k_3 for the eight blocks.*

Block	k_3
1	-1268.5
2	-1752.0
3	-3172.5
4	-2548.2
5	-559.0
6	-801.3
7	-713.3
8	-1062.0
Mean	-1484.6

The value of the covariance of mean and mean square is -187.26 , and the blocks with lower average height measurements therefore possess higher variance. The eight values of k_3 given in Table III are all negative, indicating a definite skewness within blocks.

The above considerations show that the actual distribution of the data is decidedly skew, and that the measurements exhibit different levels of fertility associated with differing variance; the material is therefore suitable for a practical test of the validity of modern statistical experimental methods when applied to irregularly distributed quantities of the type often encountered in agricultural trials.

EXPERIMENTAL METHOD.

In order to fulfil the second condition recorded in the introductory section it was necessary to use the data exactly as in an ordinary agricultural experiment. By a process of amalgamation the eight sets of 32 observations were reduced to eight sets of four and the data treated as a potential lay-out for a 32-plot trial. An actual experiment would involve the use of treatments, so four hypothetical treatments, A, B, C, D, were included, replicated in eight randomised blocks. Such an arrangement gives the following partition of degrees of freedom.

	Degrees of freedom	Sum of squares
Blocks	7	<i>a</i>
Treatments	3	<i>b</i>
Residuals	21	<i>c</i>
Total	31	<i>d</i>

If evidence can be adduced showing that the distribution of z for treatments versus residuals is statistically identical with what would be expected from normal data, there need be no hesitation in applying the z test for establishing significance to data of this type when real treatments are applied to the plots. By taking a sufficiently large number of sample arrangements of these data and classifying the calculated values of z according to the probability classes appropriate to normal data, a comparison of the actual and the theoretical distribution can be made. Since the 1 and 5 per cent. points are most important a thousand samples have been drawn from the data so as to give reasonable frequencies at the ends of the probability range.

In order to reduce the burden of computation certain modifications have been introduced. It will be noticed that the block sum of squares and the total sum of squares are constant for all samples, and thus the sum of the treatment and residual sums of squares must also be constant.

Consequently the value of z for any one sample is uniquely defined by the value for that sample of the treatment sum of squares, and instead of computing z for each sample we may stop the computation at some function of the treatment sum of squares and investigate the distribution of this quantity. All that is further required is the calculation of the hypothetical values of this function corresponding with the 5, 10, 15, ... per cent. values of z . The most convenient function for computation is the sum of the squares of the treatment totals.

It is clear that the addition or subtraction of a constant quantity to all the yields of any one block affects only the block sum of squares and the total sum of squares. In order, therefore, to keep the numerical values as low as possible (but still positive) the height measurements of all the plots in each block were reduced by the value of the lowest measurement in that block, thus giving one zero value in each block.

The method of expeditiously arriving at the sum of squares of treatment totals for so many samples may be of interest. For any given sample the four different treatments, A, B, C, D, must be assigned at random to the four plots of each block. The number of possible ways of arranging four treatments within one block is 24, and therefore the total number of ways of assigning the plots in all the blocks to the different treatments is 24^8 . For each sample it is necessary to make a random selection of one of all these possible ways.

To do this the height measurements of each block were written down in all of the 24 possible ways, each of these arrangements being given a key-number from 1 to 24. Each sample was then selected by making a random choice eight times from the numbers 1-24 by means of Tippett's tables (15), the particular set of eight key numbers so obtained being used to determine the arrangement of the treatments in the eight blocks.

To facilitate the computation of the treatment totals the apparatus illustrated in Fig. 3 was devised. The 24 arrangements of the four height measurements of the first block were written down at the head of four columns on 24 sheets of paper, one arrangement to each sheet, the entry for each column occupying the same relative position on each sheet. The 24 arrangements of the second and subsequent blocks were then entered consecutively below in the columns of the same 24 sheets, the final arrangement being such that the 32 measurements on each sheet appeared in four columns according to their treatments, and eight rows according to their blocks. The sheets were then bound up together in book form, and strips cut out between each row of figures. The eight sections of the 24 sheets, thus created, were thumb-indexed with the

numbers 1-24. Since any number 01-96 might be obtained from Tippett's tables (97, 98, 99 and 00 being rejected) the numbers 1-96 were written at the head of the index in four rows as shown. The number 63, for example, was regarded as indicating the key number 15.

In the selection of a sample, the section of each block in turn was opened at the appropriate arrangement as its key number was obtained from Tippett's tables. The height measurements were thus presented arranged in four columns according to their treatments ready for immediate summation on a printing adding machine.

				1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24																								
				25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48																								
				49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72																								
				73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96																								
				A	B	C	D																					
O	100	92	0	108	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	71	0	119	170	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	197	0	149	161	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	0	334	140	90	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
O	75	43	0	6	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	0	12	269	337	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	0	184	71	195	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	104	100	0	116	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

Fig. 3. Sampling apparatus.

The computation of the sums of squares of treatment totals was checked at two points. The treatment totals were summed, the grand total being used as a verification of the accuracy of the individual entries. In subsequently squaring the totals, the use of a tally counter on the calculating machine obviated a confirmatory calculation: providing that the multiplicand was read from the keyboard, the appearance of the grand total on the tally register served as a check on both the original entries on the keyboard and on the operation of squaring. The copying of the figures from the machine was also checked. In the classification of the thousand samples probability intervals of 5 per cent. were used with the addition of the 1, 2, 98 and 99 per cent. points.

THE z DISTRIBUTION.

The distribution of the 1000 samples is given in Table IV. The first column gives the probability limits referred to above; the theoretical z values for those probabilities follow in the second column. Column 3 gives the corresponding function of the treatment sum of squares by means of which the data have been grouped. From the expected and observed values x^2/m (deviation squared/expected value) has been tabulated for the calculation of χ^2 .

Table IV.

Frequency distribution for limiting values of P

P not exceeding	z	$\Sigma (\tau^2)$	Expected	Observed	x^2/m
0.01	0.7920	34009	10	7	0.90
0.02	0.7016	33201	10	11	0.10
0.05	0.5612	32026	30	25	0.83
0.10	0.4304	31039	50	62	2.88
0.15	0.3380	30414	50	42	1.28
0.20	0.2619	29945	50	57	0.98
0.25	0.1944	29564	50	50	—
0.30	0.1320	29241	50	42	1.28
0.35	0.0724	28956	50	36	3.92
0.40	0.0142	28701	50	62	2.88
0.45	-0.0437	28468	50	64	3.92
0.50	-0.1024	28253	50	50	—
0.55	-0.1628	28050	50	40	2.00
0.60	-0.2261	27859	50	49	0.02
0.65	-0.2937	27675	50	46	0.32
0.70	-0.3675	27498	50	51	0.02
0.75	-0.4502	27324	50	50	—
0.80	-0.5465	27152	50	48	0.08
0.85	-0.6645	26978	50	55	0.50
0.90	-0.8226	26797	50	51	0.02
0.95	-1.0790	26598	50	47	0.18
0.98	-1.4060	26453	30	29	0.33
0.99	-1.6416	26393	10	16	3.60
1.00		26293	10	10	—
$\chi^2 (P=0.50) 22.337$			$\chi^2 (P=0.30) 26.018$		$\chi^2 25.74$

Fig. 4 is a histogram of the observed frequencies plotted against a scale of P , and Fig. 5 a similar histogram plotted against a scale of z , and superimposed on the theoretical z distribution. In the first histogram all samples giving values of P between 0 and 0.05 have been included in a single group, as have those giving values of P between 0.95 and 1. The theoretical variability of each group of samples is therefore the same. In the second histogram the end groups, 0-0.05 and 0.95-1, are shown as triangles with arbitrarily chosen bases; by this means the difficulty of infinitely extensive terminal classes is overcome.

The observed frequencies agree remarkably well with those expected. There is a complete absence of trend; eight of the frequencies are in excess

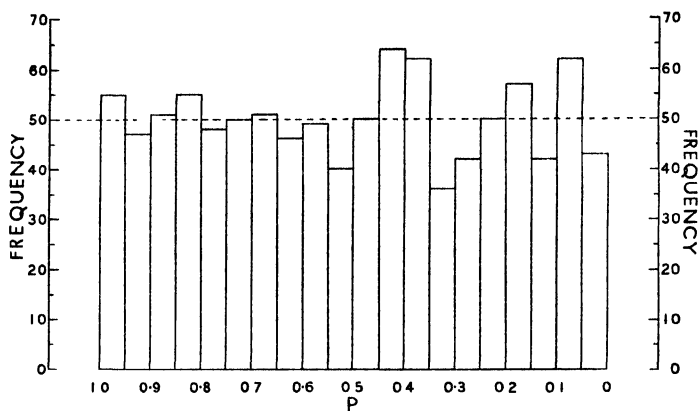


Fig. 4. Frequencies for equal intervals of P . The dotted line shows the expected value.

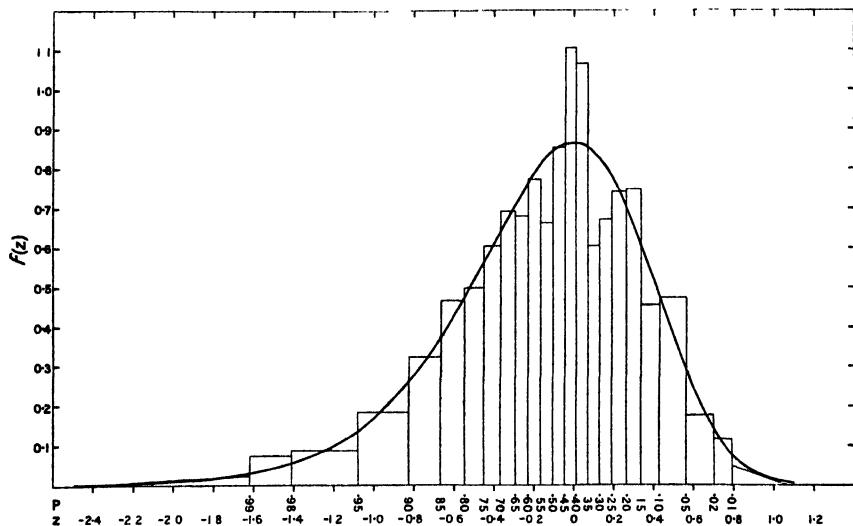


Fig. 5. The z distribution and histogram of observed frequencies.

of the expected value, nine fall short, and three coincide. There is a very good semblance of balance about the theoretical datum line, the most noticeable feature being the wider dispersion in the range of lower probabilities. The χ^2 test gives a value of 25.74, which represents a probability

rather greater than 0.30; this may be taken as satisfactory evidence that the deviations from expectation are within the errors of random sampling.

The results of this investigation, which deals with an actual experimental distribution of a definitely skew nature and with a population extending over a wide range of values, show that in actual practice there is little to fear in the employment of the analysis of variance and the z test to data of a similar type. It appears probable that in agricultural trials variable productivity of land and plant material will not invalidate the interpretation of results drawn from the statistical processes now commonly associated with them.

SUMMARY.

1. Previous work on the validity of the t and z tests on non-normal distributions is described. The question as to whether these tests, which are all on small samples from theoretical distributions, are really apposite is discussed.

2. The necessity of making a practical test with actual data which shall comply with the usual conditions obtaining in agricultural experiments is urged.

3. A practical test has been made on a skew distribution obtained from the observation of 256 height measurements on wheat. The distribution of the values of R. A. Fisher's z from a thousand random samples has been obtained and found to agree satisfactorily with the theoretical distribution.

4. These results indicate that the z test may safely be applied to data of this type.

We desire to put on record our thanks to Dr R. A. Fisher for his interest and advice during the process of the investigation, to Mr D. J. Watson who provided us with the original data, and to Sir John Russell for extending to one of us (T. E.) the hospitality of the Rothamsted Laboratories.

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(Received August 6th, 1932.)

[*Reprinted from the Journal of Agricultural Science*, Vol. XXIII. Part I.]

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THE PRINCIPLES OF ORTHOGONALITY AND CONFOUNDING IN REPLICATED EXPERIMENTS.

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(With Seven Text-figures.)

I. INTRODUCTION.

IN the past few years the procedure of the analysis of variance, developed by Dr R. A. Fisher, has been widely employed in agricultural experimental work, in conjunction with suitably designed field trials, and in consequence has been used more and more by experimenters who have little statistical training. The actual computations necessary for the analysis of a well-designed experiment are extremely simple, and even the more complex experiments can be dealt with by repeated applications of what is essentially one process. This simplicity depends on the fact that the experiments are designed so as to be orthogonal. In cases of non-orthogonality the analytical procedure must be considerably modified.

Orthogonality is that property of the design which ensures that the different classes of effects to which the experimental material is subject shall be capable of direct and separate estimation without any entanglement. In a randomised block experiment, for instance, in which every treatment occurs once in every block, the fertility differences between the different blocks can be estimated from the differences of the means of all the plots within each block, since an increase in the effect of any one treatment will increase each block mean equally (at least in so far as the treatment effect is independent of fertility level); similarly the treatment effects may be estimated by the differences of treatment means, which are unaffected by differences in fertility in different blocks. In such an experiment blocks and treatments are said to be orthogonal with each other. If, however, each block contains plots receiving some of the treatments only, comparisons between treatments will be affected by differences of fertility between the blocks, and similarly comparisons

between blocks will be affected by differences between the effects of the treatments. The blocks and treatments are then no longer orthogonal.

Lack of orthogonality may be due to accident, as when some of the plots of a field trial suffer from damage, so that their yields are virtually unknown; it may be due to some error of design; or it may be unavoidable owing to the nature of the material, as for instance in livestock trials on animals of which the sex cannot be determined at the commencement of the experiment, for then sex and treatments will be non-orthogonal. In all these cases non-orthogonality is a disadvantage, complicating the analysis, and lowering the efficiency of the experiment.

The first part of this paper contains an account of the methods of analysis appropriate to the various types of non-orthogonality, except that caused by a few missing values, which can be more appropriately discussed separately. The experiment on sugar beet carried out at the Rothamsted Experimental Station in the year 1929, which was in some respects non-orthogonal, is taken as an example; the original analysis has been described in a paper by J. Wishart⁽¹⁾, the experiment being treated as if it were orthogonal, and the results and methods there given therefore require correction.

Non-orthogonality is sometimes deliberately introduced into experimental design as a consequence of what is termed confounding. If, in order to keep the number of plots in each block of a complex experiment small, complete replication within each block is sacrificed, certain treatment differences will be entangled with fertility differences between blocks, so that treatments and blocks are non-orthogonal as far as these differences are concerned. Descriptions of experiments involving this principle have already been published^(2, 3), but no very explicit account of the underlying theory has been given. Methods have recently been devised which put the analysis of confounded experiments on a more satisfactory basis, and these should do much to remove the distrust which has sometimes been felt at its use. There is no doubt that confounding considerably widens the scope of experiments of the complex type, which embody questions on several different points. Such experiments are by far the most efficient, and in addition give conclusions which, being founded on a wider inductive basis, are of more certain validity^(2, 4). Any method which enables this type of experiment to be more widely employed is therefore likely to be of great practical utility.

In confounded experiments, where the non-orthogonality is deliberate, the design should be such that the ordinary methods of analysis require very little modification, a slight rearrangement of the data enabling the

orthogonality which was apparently lost to be regained. The discussion of confounding given in this paper does not pretend to be exhaustive, only the general principles underlying the simpler types of confounding being dealt with. There is wide scope for the design of new experimental patterns, and the complete enumeration of the more simple types would be well worth while. On the other hand there is no need to await such enumeration before making use of the principle, and the present discussion should enable the experimenter to devise designs to suit his own particular needs.

II. GENERAL DISCUSSION OF NON-ORTHOGONALITY.

In an ordinary replicated field experiment of the randomised block or Latin square type the differences of the means of plots receiving the same treatments are taken without hesitation to be true measures of treatment differences, but this is only so because the experiment has been specially arranged so as to be orthogonal. What exactly happens in cases of non-orthogonality may best be illustrated by a concrete example. Suppose that it is desired to determine the effect of two treatments on the growth of chickens, these treatments being applied each to one-half of a batch of chickens. (The chickens which are to receive the first treatment must of course be chosen at random and be kept in the same pen as the others.) In the absence of a method determining the sex at hatching the proportion of cockerels in the two groups will not be the same, and since cockerels grow faster than pullets the treatment which happens to have been given to the group containing the greater number of cockerels will clearly be given an unfair advantage if the average final weight of each group is taken as a measure of treatment effect.

In non-orthogonal experiments the ordinary methods of the analysis of variance require modification. It is true that if sex were neglected in the experiment described above differences in the mean effect of treatments which were in reality due to sex would not in general be judged significant in an ordinary analysis, since the estimate of error would be increased, but it is clear that more accurate conclusions can be drawn if the effect of sex is eliminated.

The methods of the analysis of variance applicable to a classification with unequal numbers in the different classes are well known (6), § 44). The variance between classes and the variance within classes can be simply calculated and compared by means of the z test. The variance within classes furnishes a valid estimate of "error" in the sense ordinarily

implied by that term. If, however, the various classes (here called sub-classes) can themselves be arranged in a multiple classification¹ new problems arise. Analogous difficulties are encountered in cases where the error is estimated from some interaction of an incomplete multiple classification.

A general method of analysis, which is applicable to all experiments with multiple classifications, is provided by the fitting of constants by the method of least squares. Tests of significance are made by fitting constants to represent all effects other than the one to be tested, evaluating the residual variance between classes after fitting has been performed, and comparing this variance with the intraclass variance. For example, in order to test whether any interaction between treatments and sex exists in a poultry experiment of the type already described, constants representing treatments and sex can be fitted, and the residual variance between classes after this fitting can be tested for significance by means of the z test.

This test of significance presupposes that there is an intraclass variance with which to compare the residual variance. When the error is estimated from some interaction, there being only a single member of each sub-class, and the multiple classification is incomplete, the fitting of constants also provides a method of obtaining the error interaction variance. Agricultural replicated field trials which have one or more plot yields missing, or are subject to some defect of design, so that orthogonality is not secured, may be dealt with by this method.

The fitting of constants serves a further purpose. It is frequently reasonable to suppose that the interactions between the main effects are negligible. If this is so (the experiment itself will furnish evidence on the point) the most efficient estimates of the magnitudes of the main effects may be made by fitting constants to represent these effects only. The significance test for any set of effects estimated on this assumption can be made by the method of residual variance described above.

If the interactions cannot be ignored the efficient estimates of the main effects are the means of the sub-class means (assuming the multiple classification to be complete). In orthogonal experiments these estimates are precisely the same as those obtained on fitting constants to represent the main effects only. In orthogonal experiments, therefore, there is no

¹ The term *multiple (double, triple, etc.) classification* is used to denote a simultaneous classification of several different sets of classes; the term *n-fold classification* is used to denote an ordinary classification containing n classes, which may themselves form one set of classes from a multiple classification. Thus a 5×5 Latin square would be described as a triple five-fold classification, with one member in each sub-class.

need to consider whether the interactions are in fact negligible, when estimating the main effects. In experiments where some of the sub-classes are missing entirely we can make no estimate at all of the average main effects unless we assume that some at least of the interactions are negligible. This is an extreme case, and as orthogonality is approached more and more nearly the estimates based on the two different assumptions become closer and closer. It is important to notice, however, that there are two separate tests of significance based on these different assumptions in all non-orthogonal experiments. On the other hand, since it is logically impossible that an interaction should exist without a main effect, the significance of main effects should strictly be tested on the assumption that their interactions are negligible, no test at all being necessary if the interactions are significant. The tests based on the assumption that the interactions exist are, however, simpler, and may be used with safety in cases which approach orthogonality.

Although the fitting of constants always provides efficient estimates and tests of significance the process is one which involves lengthy calculations, especially in the more complex types of experiment, and it is therefore important to utilise shorter methods when these are available. The following is a list of tests which can be made on non-orthogonal data without fitting constants in cases where an estimate of intraclass variance is available.

(1) Any set of main effects may be tested on the assumption that all other main effects and all interactions exist and are not negligible.

(2) The same test may be applied to any set of interactions of which the variance can in orthogonal cases be calculated from the sum of the squares of the deviations of a set of numbers from their mean (*e.g.* the interactions of a $2 \times n$ table, which can be calculated from the differences of the two rows of entries).

(3) An experiment in which each classification is two-fold only (*i.e.* of which the results can be arranged in a $2 \times 2 \times 2 \times \dots$ table) can be completely analysed whether interactions are assumed to exist or not. The same methods are applicable to experiments which are only partially two-fold.

(4) A useful approximate method is available which is applicable to all cases except those where some of the sub-classes of a multiple classification are missing entirely. The method can be extended to cases where only a few sub-classes are missing by means of the missing plot technique⁽⁶⁾ which can, by a process to be described in a later paper, be usefully employed even when more than one plot is missing.

The procedure of fitting constants and the shorter methods of this list are illustrated in the next section.

Although when orthogonality is not attained the procedure of the analysis of variance appropriate to orthogonal experiments breaks down its failure is not always immediately apparent, and consequently serious errors may be introduced. It is therefore important that even experimenters who ordinarily have to deal only with orthogonal data should be able to recognise the cases of non-orthogonality which may occasionally occur through some defect in design or through some accident. Certainly anyone who wishes to employ the methods of confounding, discussed in the later sections of this paper, in the design of experiments must have clear ideas on orthogonality, or he may find himself faced with the analysis of experiments involving lengthy and cumbersome calculations.

III. METHODS OF ANALYSIS.

Fitting constants.

The method of fitting constants (7, 8) may best be illustrated in its application to a concrete example. Table I shows results such as might be obtained in a poultry experiment of the type already described, but with three treatments (the numbers of birds in each class being shown in brackets).

Table I. *Mean weight per bird.*

Treatment	A	B	C
Cockerels	2.82 (5)	2.50 (9)	2.75 (12)
Pullets	1.99 (10)	1.83 (6)	1.82 (3)
Mean	2.405	2.165	2.285

The estimate of the variance within classes, σ^2 , which can be computed from the deviations of the individual bird weights from the sub-class means shown in the table, is taken as 0.0786. This will be based on 39 degrees of freedom.

In order to test the significance of the interactions between treatments and sex, constants representing the direct treatment and sex effects must be fitted. The procedure is as follows. Taking constants t_1, t_2, t_3 to represent the mean weights of equal numbers of cockerels and pullets subjected to the three treatments, and $2c$ to represent the mean difference between cockerels and pullets, w being the weight of an individual bird, the values of the constants must be so chosen as to minimise

$$S \{w - (\pm c + t_s)\}^2,$$

where the summation is taken over all birds, the signs of c and the particular t being chosen according to the scheme of Table II.

Table II.

Treatment	A	B	C
Cockerels	$t_1 + c$	$t_2 + c$	$t_3 + c$
Pullets	$t_1 - c$	$t_2 - c$	$t_3 - c$

The equations for determining the values of the t and c can be written down by the method of least squares. Reference may be made to (5), § 29, where the application of the method to partial regressions is given. The method here is formally the same: c, t_1, t_2, t_3 correspond to the regression coefficients b, w to y , and the equations

$$W = \pm c + t_i$$

to the regression equation

$$Y = b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4,$$

the values of all x being limited to ± 1 and 0. Thus the equations for determining the t and c are obtained by forming the set of equations

$$b_1S(x_1^2) + b_2S(x_1x_2) + b_3S(x_1x_3) + b_4S(x_1x_4) = S(x_1y),$$

etc., with the special values of x and y relevant to this particular experiment, the summation being taken over each individual bird. For this purpose it is useful to make out a table of the total weight of all birds in each class (Table III).

Table III. *Total bird weight.*

Treatment	A	B	C	Total
Cockerels	14.10 (5)	22.50 (9)	33.00 (12)	69.60 (26)
Pullets	19.90 (10)	10.98 (6)	5.46 (3)	36.34 (19)
Total	34.00 (15)	33.48 (15)	38.46 (15)	105.94 (45)

The equations can now be immediately written down. They are

$$\begin{array}{rclcl}
 45c & - 5t_1 & + 3t_2 & + 9t_3 & = 33.26, \\
 - 5c & + 15t_1 & & & = 34.00, \\
 + 3c & & + 15t_2 & & = 33.48, \\
 + 9c & & & + 15t_3 & = 38.46.
 \end{array}$$

The numerical solution is

$$c = 0.3970, \quad t_1 = 2.3990, \quad t_2 = 2.1526, \quad t_3 = 2.3258.$$

We are now in a position to determine whether the assumption of negligible interaction is in fact justified. The fitting of the constants t and c will account for 3 degrees of freedom (after allowance has been made for the mean). The reduction in the total sum of squares due to the fitting, given by the general formula

$$S(y^2) - S(y - Y)^2 = b_1 S(x_1 y) + b_2 S(x_2 y) + b_3 S(x_3 y) + b_4 S(x_4 y),$$

is therefore

$$33.26 \times 0.3970 + 34.00 \times 2.3990 + \text{etc.} = 256.2895.$$

This includes the correction for the mean, 249.4064, and therefore the additional reduction in the sum of squares above that obtained by fitting the mean only is 6.8831. The total sum of squares between classes is 6.9872, and the analysis of variance may therefore be set out as in Table IV.

Table IV.

	Degrees of freedom	Sum of squares	Mean square
Constants c and t	3	6.8831	2.2944
Remainder (interaction)	2	0.1041	0.0520
Between classes	5	6.9872	
Within classes	39	3.0654	0.0786
Total	44	10.0526	

If the remainder of the sum of squares between classes (2 degrees of freedom) gives a variance significantly above that within classes it is evidence that the hypothesis that the effects of sex and treatments are additive is not justified, or in other words that interaction between sex and treatments exists. In this experiment there is clearly no evidence of interaction.

The significance of the direct effects of treatments may now be tested on the assumption of negligible interaction. This is done in a similar manner to the test for interaction, the residual variance after fitting a constant for sex only being obtained from the 3 degrees of freedom for sex and treatments. The sum of squares due to fitting the constant c only, 6.4128, can be immediately calculated from the total column of Table III, being the sum of squares between classes when treatments are ignored. The analysis is therefore:

	Degrees of freedom	Sum of squares	Mean square	z
Sex, neglecting treatments	1	6.4128	6.4128	
Remainder (treatments)	2	0.4703	0.2352	0.5480
Sex and treatments	3	6.8831		

The 5 per cent. point of z is 0.5876, and the effect of treatments as a whole cannot therefore be regarded as unquestionably significant.

In a similar manner the test for the effect of sex may be thrown in the analysis of variance form. The analysis will be:

	Degrees of freedom	Sum of squares	Mean squares
Treatments, neglecting sex	2	0.9992	0.4996
Remainder (sex)	1	5.8839	5.8839
Sex and treatments	3	6.8831	

It will be seen that the variance ascribable to treatments, neglecting sex, is considerably higher than the treatment variance. No relevant test of significance can be made on this variance, however, since it contains sex as well as treatment effects. The total bird weight for treatment *C*, 38.46, for example, is too high because of the large proportion of cockerels in this group.

The level of significance of sex and treatments, tested separately, may either be higher or lower than that of the combined effect. In extreme cases it may happen that although the variance corresponding to the 3 degrees of freedom for the constants c and t is significant, implying that either sex or treatments or both produce an effect, neither sex nor treatments, when tested separately, appears significant. The reason for this may easily be seen if we consider the case of an experiment with two treatments, where all the birds receiving treatment *A* are cockerels and all those receiving treatment *B* are pullets; it is then clearly impossible to isolate the effects of sex and treatment, however accurate the experiment.

The test for the significance of the direct effects of treatments when the interaction is not assumed to be negligible might be made on similar lines to the test for the significance of interactions, constants representing sex and the interactions being fitted. A shorter and more convenient procedure for this test is given below.

It is of interest to see how the method of fitting constants reduces to the ordinary recognised method of analysis when the data is orthogonal. The essential point of orthogonal data is that the numbers in the various classes are such that variation of one set of effects does not alter the totals representing any other set of effects. Mathematically this implies that all the product sums, $S(x_1x_2)$, etc., of the equations for determining the fitted constants are zero. If this is so each equation contains only one constant, and can be solved immediately, the value so obtained being the

same whether or not all the other constants are fitted at the same time. The reduction in the sum of squares due to fitting reduces to

$$\frac{\{S(x_1y)\}^2}{S(x_1^2)} + \frac{\{S(x_2y)\}^2}{S(x_2^2)} + \dots,$$

from which it follows that the reduction in the sum of squares due to the fitting of one set of constants is the same whether other sets are fitted or not. From this the whole procedure of the analysis of variance as applied to orthogonal experiments can be immediately deduced.

In agricultural field experiments there is not usually replication within each class; in an ordinary randomised block experiment, for instance, each treatment occurs once only within each block, and the estimate of error variance is obtained by the interaction of blocks and treatments. Such experiments are ordinarily designed so as to be orthogonal, but if through some cause, either intended or accidental, non-orthogonality is introduced, the methods of analysis must be suitably modified, or serious errors will result. In some cases the missing plot technique is applicable, while in others (more particularly well-designed confounded experiments) the analysis can be so modified as to create virtual orthogonality, but in certain cases the only suitable method of full analysis is that of fitting constants. An example of this type is given later in the paper. In any event it is important to notice that an unjustified assumption of orthogonality will lead not only to false treatment variances, but also to a false error variance.

It may perhaps be as well to recall here that it is possible to test any linear function of the fitted constants by means of the t test. In R. A. Fisher's notation (5), § 29, if the solution of the set of equations for c and t be $c_{11}, c_{12}, c_{13}, c_{14}$, when 1, 0, 0, 0, are substituted for the numerical terms of the four equations, and $c_{21}, c_{22}, c_{23}, c_{24}$, when 0, 1, 0, 0, are substituted for the numerical terms, etc., then the variance of any linear function of c and t ,

$$x = l_1c + l_2t_1 + l_3t_2 + l_4t_3,$$

is given by

$$V(x) = \{l_1^2c_{11} + l_2^2c_{22} + \dots + 2l_1l_2c_{12} + \dots\} \sigma^2,$$

it being noted that $c_{12} = c_{21}$, etc.

In our example the values of c_{11} , etc., are

225	75	— 45	— 135
75	585	— 15	— 45
— 45	— 15	569	27
— 135	— 45	27	641

all divided by 8400. These values can, of course, be used to determine the values of the constants themselves.

The estimate of the difference of treatments *A* and *B*, for example, is $t_1 - t_2$, or 0.2464. The variance of this quantity is given by

$$V(t_1 - t_2) = \sigma^2 (1 \times 585 + 1 \times 569 + 2 \times 15)/8400 = 0.1410\sigma^2.$$

The estimate of the standard deviation is therefore 0.1053 (39 degrees of freedom) and t is in the neighbourhood of the 1 in 50 point. This, however, is the greatest of the three differences, and unless there is *a priori* justification for singling out this difference for special examination the test cannot be considered valid.

Variance from weighted squares of means.

Instead of fitting constants it is possible to perform a direct test for treatments on the means of Table I. The variances of the three treatment means are $\frac{1}{4}(\frac{1}{6} + \frac{1}{10})\sigma^2$, $\frac{1}{4}(\frac{1}{6} + \frac{1}{8})\sigma^2$, and $\frac{1}{4}(\frac{1}{12} + \frac{1}{8})\sigma^2$, or $\sigma^2/13.3333$, $\sigma^2/14.4$, and $\sigma^2/9.6$. The efficient estimate of σ^2 from these means is therefore

$$\frac{1}{2} \left[\begin{aligned} &2.405^2 \times 13.3333 + 2.165^2 \times 14.4 + 2.285^2 \times 9.6 \\ &- \frac{(2.405 \times 13.3333 + 2.165 \times 14.4 + 2.285 \times 9.6)^2}{13.3333 + 14.4 + 9.6} \end{aligned} \right],$$

as can be seen on the analogy of interclass variance with unequal numbers in the various classes. The numerical value of this variance is 0.1995, as compared with the value 0.2352 previously obtained, but the two tests are on a different basis, only the first being made on the assumption of negligible interaction. It can be shown that the present test is efficient if interaction is not to be neglected, the variance obtained being identical with the residual variance when constants representing sex effect and interaction are fitted. That this is so is clear on general grounds, since if interaction exists the three treatment means contain all the information possible on average treatment effect.

This suggests an alternative method of testing the significance of the interactions, which may be estimated from the differences of mean bird weight between cockerels and pullets for treatments *A*, *B* and *C*. These differences are 0.83, 0.67 and 0.93 respectively, and their variances are four times the variances of the corresponding treatment means. The estimate of σ^2 can be made in exactly the same manner as was employed in the case of the treatment means, the value obtained, 0.052032, agreeing precisely with that obtained by the method of fitting constants. This

method of computation is obviously preferable to the method of fitting constants, but it is only applicable to interactions when these are capable of direct calculation from differences, as is the case in any classification of the $2 \times 2 \times 2 \times \dots \times n$ type.

The method of weighted squares provides a useful test for the main effects in cases where these effects may appropriately be estimated by the direct means of the sub-class means, that is in cases which approach orthogonality or where the assumption of negligible interaction is not justified. With negligible interactions and widely differing numbers in the different classes, and particularly when some of the classes are missing entirely, a considerable amount of information may be lost, and in such cases the fitting of constants should be resorted to, at any rate if the data justify the extra labour.

The actual amount of information lost, on the assumption of negligible interaction, by the alternative method, can only be determined in any particular experiment after the values of c_{11} , etc., have been found. If the intraclass variance is denoted by B , and the variance ascribable to treatment effects by A (5, § 40), it is possible to evaluate the expectation, in terms of A and B , of the treatment variances obtained by the two methods of analysis. In the particular example given that of the method of fitting constants is $13.8765 A + B$, while that of the other method is $12.2742 A + B$. Thus 89 per cent. of the information is utilised by the second method.

Multiple two-fold classifications.

When interactions are assumed to exist experiments containing only two-fold classifications may clearly be completely analysed by the method of weighted squares of means; in this type of classification the method is equivalent to the simpler approximate method described below. The direct effects may also be estimated and tested for significance on the assumption of negligible interaction, by a method now to be described. The same method may be applied to the two-fold parts of experiments not wholly two-fold, and the procedure may therefore be illustrated by applying it to the sex difference in the example already given.

If the interaction be negligible the best estimate of the difference between cockerels and pullets will be obtained by taking the weighted mean of the differences for treatments A , B and C . These differences are 0.83, 0.67 and 0.93, their variances being $(\frac{1}{6} + \frac{1}{10}) \sigma^2$, $(\frac{1}{5} + \frac{1}{8}) \sigma^2$ and $(\frac{1}{12} + \frac{1}{3}) \sigma^2$. Weighting inversely as the variances, the weighted mean 0.7940 is

obtained. Its variance will be the reciprocal of the sum of the reciprocals of the above variances, or $0.107143\sigma^2$. The significance can be tested in doubtful cases by the t test. It should be noticed that the above estimate is precisely equal to the estimate, $2c$, obtained by fitting constants, and that its variance is equal to the variance of $2c$ calculated from c_{11} .

When the interaction sum of squares is calculated by the method of weighted squares of means, instead of by fitting constants, the differences of t_1 , t_2 and t_3 will not be available as estimates of the treatment differences. Instead the weighted means of the differences for cockerels and pullets may be employed. The differences between treatments A and B , for instance, are 0.32 and 0.16 respectively, with variances $(\frac{1}{5} + \frac{1}{10})\sigma^2$ and $(\frac{1}{10} + \frac{1}{5})\sigma^2$. Weighting inversely as these variances the weighted mean 0.2338 is obtained, with variance $0.1436\sigma^2$. This should be compared with the efficient estimate already obtained from the difference of t_1 and t_2 . If instead of the weighted mean of the differences the unweighted mean, 0.24, had been taken, on the assumption of negligible interaction a slightly less efficient estimate would have been obtained. If, however, the interaction is not to be neglected the unweighted mean provides the efficient estimate of the treatment differences. The values of the three sets of estimates, their variances, and their efficiency on the assumption of negligible interaction, is given in Table V. In this experiment there is little loss of accuracy in using the weighted means, and very little additional loss in using the unweighted means, except for $C-B$.

Table V.

	Estimates			Variances/ σ^2			Efficiency	
	Efficient	Weighted means	Un-weighted means	Efficient	Weighted means	Un-weighted means	Weighted means %	Un-weighted means %
$A-B$	0.2464	0.2338	0.24	0.1410	0.1436	0.1444	98	98
$A-C$	0.0732	0.1095	0.12	0.1563	0.1713	0.1792	91	87
$C-B$	0.1732	0.1828	0.12	0.1376	0.1402	0.1736	98	79

Approximate analysis of variance.

It is possible to perform an ordinary analysis of variance on the table of mean bird weights (Table II) on the assumption that each mean bird weight has an equal variance, the error variance being taken as the mean of the variances of the various mean bird weights, or

$$\frac{1}{8} \left(\frac{1}{5} + \frac{1}{10} + \frac{1}{5} + \frac{1}{5} + \frac{1}{12} + \frac{1}{3} \right) \sigma^2,$$

of which the estimate from the intraclass variance is 0.01302. The

analysis now reduces to the ordinary orthogonal form, provided there are no missing classes, the values obtained being given in Table VI.

Table VI.

	Degrees of freedom	Sum of squares	Mean square
Treatments	2	0.05760	0.02880
Sex	1	0.98415	0.98415
Interaction	2	0.01720	0.00860
Intraclass	39	—	0.01302

Although the z distribution will not hold exactly it does not seem likely that any great disturbance will be introduced. Apart from this the method is equivalent to throwing away the information on the distribution of the class numbers amongst the various classes.

The chief utility of this approximate method lies in the testing of interactions of complex experiments which could otherwise be tested only by fitting constants. In the analysis of multiple two-fold classifications it is equivalent to the analysis by the method of weighted squares of means, and therefore provides a rigorous method when interactions are not negligible. (This equivalence, which depends on a simple algebraic identity, must follow from general considerations, and need not be demonstrated here.)

IV. THE CONFOUNDING OF MAIN EFFECTS.

In agricultural varietal trials it is frequently impracticable, owing to sowing difficulties, to use such small plots as are possible in manurial experiments. It is, moreover, often desirable to introduce different varieties into manurial trials, and *vice versa*, in order to give a wider inductive basis to any conclusions that may be drawn. This has led to the simple expedient of sowing large plots with each variety and subdividing these plots into smaller ones for the purposes of manurial comparisons.

The simplest type of lay-out of this nature is that of complete replication of the manurial treatments within each plot of the varietal treatments. An extended nomenclature will be necessary. We will call the varietal treatments of the above example the *main treatments*, the varietal plots the *main plots*, the manurial treatments the *sub-treatments*, and the manurial plots the *sub-plots*. Fig. 1 gives the plan of an experiment of this type, with the main plots arranged in randomised blocks.

The analysis of variance presents no great difficulties. Since every sub-treatment occurs once in each main plot the differences between main plots will properly represent the average main treatment effects for sub-treatments a , b and c , and the differences in different blocks will form an

estimate of error. The first part of the analysis of variance is therefore as follows:

	Degrees of freedom
Blocks	3
Main treatments	3
Main plot error...	9
Total, main plots	<u>15</u>

The experiment may also be regarded as one of sixteen randomised blocks with three plots per block, the main plots corresponding to the blocks and the sub-plots to the plots. There is, however, this difference: the error sum of squares, which is derived from interaction between main

Block I				Block II			
A	C	B	D	B	D	A	C
a	b	a	b	a	c	c	b
c	a	b	a	b	a	a	a
b	c	c	c	c	b	b	c

Block III				Block IV			
B	C	D	A	D	C	B	A
a	a	c	a	b	c	b	a
c	c	a	b	c	a	a	b
b	b	b	c	a	b	c	c

Fig. 1. Main treatments: A, B, C, D. Sub-treatments: a, b, c.

plots and sub-treatments, may be divided into two parts, namely that due to interaction between sub-treatments and main plots having the same main treatment and that due to interaction between sub-treatments and main plots having different treatments. The second variance forms an estimate of the interaction of sub-treatments with main treatments, and this may be compared with the first variance, which forms a valid estimate of error also for the comparison of average sub-treatment differences. The second part of the analysis of variance is therefore as follows:

	Degrees of freedom
Main plots (= total of 1st part) ...	15
Sub-treatments	2
Interaction: sub- and main treatments	6
Sub-plot error	24
Total	<u>47</u>

Experiments of this nature, although they are practically convenient, are not very efficient. Sub-plot error, representing chance differences between closely contiguous plots, is in general likely to be considerably smaller than the main-plot error, which is subject to all the causes of variation which affect the sub-plots (except such as arise from certain competition effects, unequal division of plots, and the like), and also to additional causes which affect the individual main plots as a whole. The accuracy of the comparison of sub-treatments, and of the interaction of main treatments with sub-treatments, is increased over that which would be obtained from a simple four-block experiment with 12 plots per block, but only at the expense of the comparison between the main treatments. In certain circumstances this may be what is required, but in general the direct effects are of more interest than the interactions.

This type of confounding is capable of many variations. The split plot experiment, where one half of each plot receives a different treatment from the other half, this difference being superimposed on the main treatments, is an example. In general the design and analysis of such experiments is comparatively simple, and if the sub-treatments are properly randomised within each separate main plot the conclusions are of certain validity.

A variant on the same theme is illustrated in Fig. 2. Here the treatments a, b, c , are not arranged at random within each main plot, but are restricted so as to lie in strips across the whole experiment. In the figure shown the main treatments A, B, C, D , are arranged in the form of a Latin square, though the same type of arrangement would be equally applicable to a randomised block experiment. Here the analysis of variance must be divided into three parts, with errors appropriate to comparisons of main treatments, to strip treatments, and to interactions respectively. The first part consists of an ordinary Latin square analysis, the second a randomised block analysis, each column of main plots forming one block of strips, the third a sub-plot analysis with the effect of strips as well as main plots removed. The analysis can be set out as in Table VII.

Table VII.

Main treatments			Strip treatments			Interactions		
		D.F.			D.F.			D.F.
Rows ...	...	3	Columns ...	...	3	Main plots ...	...	15
Columns ...	...	3	Strip treatments ...	...	2	Deviations of strips	...	
Main treatments ...	...	3	Error ...	...	6	from columns ...	...	8
Error ...	...	6				Interactions ...	...	6
						Error ...	...	18
<hr/>			<hr/>			<hr/>		
Main plots ...	...	15	Strips ...	...	11	Total ...	...	47

This type of lay-out is given here because it has certain practical attractions. It is open to even stronger criticism on the score of efficiency than the foregoing type, since neither main nor strip treatments are as accurately determined as are the interactions.

<i>a</i>	<i>c</i>	<i>b</i>	<i>c</i>	<i>a</i>	<i>b</i>	<i>b</i>	<i>a</i>	<i>c</i>	<i>c</i>	<i>b</i>	<i>a</i>
	<i>A</i>			<i>C</i>			<i>B</i>			<i>D</i>	
	<i>B</i>			<i>D</i>			<i>A</i>			<i>C</i>	
	<i>C</i>			<i>B</i>			<i>D</i>			<i>A</i>	
	<i>D</i>			<i>A</i>			<i>C</i>			<i>B</i>	

Fig. 2.

There is one type of design which at first appears to be a simple extension of the principle already employed, but for which the ordinary analysis breaks down. If a Latin square has whole rows (or columns) subjected to different treatments, trouble arises from the fact that the interactions of the Latin square (or sub-) treatments with the main row treatments are not orthogonal with the column effects. Fig. 3 shows a lay-out of this description.

<i>A</i>	<i>b</i>	<i>d</i>	<i>c</i>	<i>a</i>	<i>c</i>	<i>f</i>
<i>B</i>	<i>e</i>	<i>a</i>	<i>b</i>	<i>f</i>	<i>d</i>	<i>c</i>
<i>B</i>	<i>a</i>	<i>b</i>	<i>d</i>	<i>c</i>	<i>f</i>	<i>e</i>
<i>A</i>	<i>c</i>	<i>e</i>	<i>f</i>	<i>d</i>	<i>a</i>	<i>b</i>
<i>B</i>	<i>d</i>	<i>f</i>	<i>c</i>	<i>b</i>	<i>e</i>	<i>a</i>
<i>A</i>	<i>f</i>	<i>c</i>	<i>a</i>	<i>e</i>	<i>b</i>	<i>d</i>

Fig. 3.

The effects of the main treatments, *A* and *B*, are clearly obtained by an analysis in the form of three randomised blocks, 1 degree of freedom

being allotted to treatments, 2 to blocks, and 2 to error. The experiment is of course not capable of giving a very precise answer on this difference. The analysis of the sub-treatments, on similar lines to that previously adopted, is given in Table VIII.

Table VIII.

				Degrees of freedom
Rows (= main plot total)	...	...	...	5
Columns	...	...	...	5
Sub-treatments	...	...	...	5
Interaction: main and sub-treatments	...	...	...	5
Sub-plot error	...	...	...	15
Total	...	...	...	<hr/>35

When we come to the computation of the interaction sum of squares a difficulty presents itself. This interaction would ordinarily be computed as the interaction of Table IX.

Table IX.

	Sub-treatments					
Main treatments	<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	<i>e</i>	<i>f</i>
<i>A</i>	—	—	—	—	—	—
<i>B</i>	—	—	—	—	—	—
Sum (<i>A</i> + <i>B</i>)	—	—	—	—	—	—
Difference (<i>A</i> - <i>B</i>)	—	—	—	—	—	—

The interaction involves a comparison of the differences (*A* - *B*). But on consideration it will be seen that these differences are not equalised for columns, the difference for *a*, for example, being made up of the sum of plots from columns 3, 4 and 5, less plots from columns 1, 2 and 6, that for *b* by plots from columns 1, 5 and 6, less plots from columns 2, 3 and 4. The comparison will therefore be affected not only by interaction differences, but also by column differences, and if the interactions are themselves negligible the sum of squares will tend to be increased. If therefore, as is usual, the error sum of squares is computed as a difference from the total sum of squares, the error will tend to be too small.

It will be seen that the sub-treatment sum of squares may be computed from the sum line (*A* + *B*) of the table, since this is equalised for both rows and columns. The sub-treatments are therefore orthogonal with the rows and columns, this being the ordinary Latin square property. The interactions are orthogonal to the rows, since each difference (*A* - *B*) is made up of the sum of plots from rows 1, 4 and 6, less plots from rows 2, 3 and 5.

To make a full analysis of such an experiment it is necessary to

evaluate the interaction sum of squares, and this can only be done by fitting suitable constants to represent these interactions, together with constants for the columns, with which the interactions are not orthogonal. The total sum of squares attributable to the 10 degrees of freedom, columns and interactions, is thus obtained, and the error sum of squares is found by deducting this and the row and treatment sums of squares from the total sum of squares. The interaction sum of squares is given by the difference of the sum of squares for the 10 degrees of freedom above and the sum of squares for columns. The whole process is analogous to that already considered in section III.

Since this process necessitates the solution of ten simultaneous linear equations (or, on reduction, five equations) the amount of computation is vastly greater than what would be required in an orthogonal experiment of similar size. This type of lay-out should therefore be avoided. It is worth noting, however, that an approximate analysis can be made on the assumption that the interactions are negligible, the 20 degrees of freedom for interaction and sub-plot error being combined and utilised as an estimate of error for sub-treatments. This procedure is justified by the fact that in agricultural experiments interactions are generally found to be small in comparison with main effects. Should the assumption not be true the computed error will be too large and the experiment will be judged to be less efficient than it really is, but no false conclusions will be reached.

The Rothamsted experiment on sugar beet already mentioned was a somewhat complex example of a lay-out of this type, columns as well as rows being subjected to additional treatments. This criss-cross pattern introduces a further complication which will be discussed in detail in the next section, which contains an outline of the correct analysis of the experiment.

V. THE ROTHAMSTED EXPERIMENT ON SUGAR BEET IN 1929.

A general description of this experiment has been published in *Arch. für Pflanzenbau*(1), but since this paper may not be readily accessible it will be as well to recapitulate the essential features here.

The experiment was originally designed as a 12×12 Latin square, the twelve treatments being made up of three nitrogen treatments, two of potash, and two of common salt, in all combinations. In addition it was desired to investigate the effect of phosphate, and to carry out the experiment on two varieties instead of one. These new factors were introduced into the original design by the artifice of sowing the rows of the Latin

	P	O	O	P	O	P	O	P	O	P	O	P	O	P	O	P	O	P	O	P	O	Row totals
J	9 15.1	3 1.0	1 - 7.6	8 2.6	4 -15.5	6 1.9	12 - 2.3	2 - 3.2	10 7.3	11 3.7	7 6.3	5 29.8										24.5
K	10 6.0	5 9.3	9 7.5	2 - 8.0	3 - 7.1	4 -10.2	8 - 4.5	1 -17.8	11 - 4.5	7 -17.8	12 0.2	6 2.9										- 44.0
J	11 28.6	1 4.6	7 8.9	12 20.6	10 6.2	3 23.7	5 7.9	4 6.8	8 8.1	6 4.4	9 8.6	2 10.6										139.0
K	6 21.1	12 9.8	2 17.1	3 17.9	9 13.7	7 9.5	10 7.8	8 13.0	1 - 1.9	4 9.2	5 12.2	11 14.9										144.3
K	8 23.5	11 19.7	6 19.7	4 0.6	1 - 3.5	5 8.3	2 2.8	9 1.6	7 0.9	10 4.5	3 - 2.1	12 5.0										81.0
J	3 28.4	7 2.8	10 - 5.1	6 10.1	5 8.7	9 15.6	11 3.3	12 7.7	4 - 3.0	2 9.8	1 -12.3	8 7.8										73.8
K	2 7.3	9 13.6	4 3.3	10 - 4.7	7 3.3	12 18.5	1 - 3.5	11 7.0	6 2.7	5 - 5.6	8 - 0.2	3 - 3.4										38.3
J	7 11.8	6 13.6	12 18.1	1 11.8	8 14.1	2 23.8	9 5.7	10 - 4.1	5 - 0.7	3 1.0	11 - 0.8	4 - 7.9										86.4
J	5 17.1	2 10.4	3 14.7	7 14.0	12 15.5	11 29.6	4 1.1	6 10.6	9 8.8	8 8.1	10 - 2.3	1 - 1.2										126.4
K	1 - 1.2	4 -10.5	8 1.7	5 - 0.4	11 - 5.8	10 - 9.8	7 5.8	3 - 2.4	2 5.0	12 4.8	6 9.3	9 1.2										- 2.3
J	12 16.2	8 10.7	5 3.5	11 12.3	2 - 6.3	1 5.9	6 16.3	7 10.6	3 7.8	9 13.1	4 7.7	10 10.9										108.7
K	4 -27.2	10 -27.0	11 -24.4	9 -24.4	6 -28.4	8 -21.0	3 -20.7	5 -12.2	12 - 5.8	11 -18.9	2 -15.3	7 -12.2										-237.5
Column totals	146.7	58.0	57.4	52.4	-5.1	95.8	19.7	17.6	10.1	16.3	11.3	58.4										538.6

Key to treatments and varieties.

Treatment...	1	2	3	4	5	6	7	8	9	10	11	12
Sulphate of ammonia	-	x	-	-	x	-	-	x	-	-	x	-
Nitrate of soda	-	-	x	-	-	x	-	-	x	-	-	x
Muriate of potash	-	-	-	x	x	x	-	-	x	x	x	x
Salt	-	-	-	-	-	-	-	x	x	x	x	x
O, No superphosphate.												
P, superphosphate.												
J, Kuhn (Johnson's Perfection).												
K, Kleinwanzleben.												

Fig. 4. Plan and yields in kg. less 80.

square with the two varieties, one of each pair of rows being allotted at random to the first variety; and similarly by treating one of each pair of columns with phosphate.

The details of the lay-out and the yields of roots per plot are given in Fig. 4. The analysis of variance, assuming the interactions of phosphate and variety with the other manurial treatments (33 degrees of freedom) are negligible, and can be classed as error, is given in Table X. All the sets of degrees of freedom classified in this table are orthogonal with one another and can be computed in the ordinary manner.

Table X. *Analysis of variance.*

		Degrees of freedom	Sums of squares	Mean square
Rows	Row pairs	5	4324.76	
	Variety	1	2328.06	2328.06
	Error	5	3651.27	730.25
		11	10304.09	
Columns	Column pairs	5	865.94	
	Phosphate	1	346.58	346.58
	Error	5	500.70	100.12
		11	1713.22	
Treatments	Nitrogen	2	2008.47	1004.24
	Potash	1	5.60	5.60
	Salt	1	203.54	203.54
	Interactions: $K \times Na$	1	34.22	34.22
	$N \times K$	2	192.47	96.24
	$N \times Na$	2	97.47	48.74
	$N \times K \times Na$	2	64.92	32.46
		11	2606.70	
Interaction: phosphate and varieties		1	234.60	234.60
Interactions: phosphate, variety, and other manures		33	4997.69	45.85
Error		76		
Total		143	19856.30	

The interactions between phosphate and other manurial treatments (11 degrees of freedom), between variety and other manurial treatments (11 degrees of freedom), and between phosphate, variety, and other manurial treatments (11 degrees of freedom) are all non-orthogonal with the rows and columns, and consequently the evaluation of the sum of squares to be allotted to them involves the fitting of appropriate constants. There will in all be 55 independent constants, and consequently 55 independent equations to solve. These equations can be immediately reduced by substitution to 22, which are fairly easily solved by iterative methods.

There is no need to give more than an outline of the analysis here. The constants were chosen according to the following scheme:

Mean	...	...	...	...	m ;
Rows	...	...	...	...	$r_1, r_2, \dots, r_{12}, (r_1 + r_2 + \dots + r_{12} = 0)$;
Columns	...	...	...	...	$c_1, c_2, \dots, c_{12}, (c_1 + c_2 + \dots + c_{12} = 0)$;
Non-phosphatic manures	...	...	...	...	$t_1, t_2, \dots, t_{12}, (t_1 + t_2 + \dots + t_{12} = 0)$;
Interaction, phosphate and variety	...	...	...	...	g ;
Interaction, phosphate and other manures	...	...	...	...	$p_1, p_2, \dots, p_{12}, (p_1 + p_2 + \dots + p_{12} = 0)$;
Interaction, variety and other manures	...	...	...	...	$v_1, v_2, \dots, v_{12}, (v_1 + v_2 + \dots + v_{12} = 0)$;
Interaction, variety, phosphate and other manures	...	...	...	...	$i_1, i_2, \dots, i_{12}, (i_1 + i_2 + \dots + i_{12} = 0)$.

The exact meaning assigned to the above constants will be clear from the following table (Table XI), showing the constants assigned to each of the 48 varietal and treatment combinations.

Table XI.

Treatments	1	2	etc.
<i>JO</i>	$t_1 - p_1 - v_1 + i_1 + g$	$t_2 - p_2 - v_2 + i_2 + g$	
<i>JP</i>	$t_1 + p_1 - v_1 - i_1 - g$	$t_2 + p_2 - v_2 - i_2 - g$	
<i>KO</i>	$t_1 - p_1 + v_1 - i_1 - g$	$t_2 - p_2 + v_2 - i_2 - g$	
<i>KP</i>	$t_1 + p_1 + v_1 + i_1 + g$	$t_2 + p_2 + v_2 + i_2 + g$	

Corresponding to the 144 plots there are 144 equations. If Y_{xyz} represents the yield of the x th row, the y th column, and the z th treatment, the equation corresponding to the fifth plot of the fourth row, for instance, is

$$Y_{459} = m + r_4 + c_5 + t_9 - p_9 + v_9 - i_9 - g.$$

The equations for determining the constants, deducible from these, are therefore

$$\begin{aligned}
 144m &= SY_{xyz}, & 1 \text{ equation} \\
 12m + 12r_a + S(\pm p)^* + S(\pm i) &= SY_{avyz}, & 12 \text{ equations} \\
 12m + 12c_a + S(\pm v)^* + S(\pm i) &= SY_{xaz}, & 12 \text{ ,,} \\
 12m + 12t_a &= SY_{xya}, & 12 \text{ ,,} \\
 144g &= S(\pm Y_{xyz}), & 1 \text{ ,,} \\
 12p_a + S(\pm r) + S(\pm c)^* &= S(\pm Y_{xya}), & 12 \text{ ,,} \\
 12v_a + S(\pm r)^* + S(\pm c) &= S(\pm Y_{xya}), & 12 \text{ ,,} \\
 12g + 12i_a + S(\pm r) + S(\pm c) &= S(\pm Y_{xya}), & 12 \text{ ,,}
 \end{aligned}$$

The \pm signs in these equations vary from equation to equation, and can only be determined by reference to the plan of the experiment. In the actual solution a key diagram of signs was prepared; the diagonal symmetry obviates the necessity of tabulating more than half the signs.

Only 68 of the 74 equations are independent. The equations for m , g and all t are free from entanglement and can be solved immediately. By means of the last 36 equations all p , v and i can be eliminated from the first two groups of 12 equations. The resultant 24 equations can then be solved by iteration. The solution converges rapidly. The fact that $S(r)$ and $S(c)$ are both zero gives two useful checks. It should be noted that the sets of terms marked with asterisks are the same for each equation of the set in which they occur, and can be evaluated numerically before substitution is begun.

After values had been obtained for all r , c , p , v and i , the reduction in the sum of squares due to fitting was calculated by means of the ordinary formula. As a check the error sum of squares was also computed directly from the residuals. The values obtained were 4015.38 and 4003.17 respectively. The agreement, though not perfect, is close enough to indicate that there is nothing seriously wrong with the fitting.

The last term of the previous analysis of variance splits up as in Table XII.

Table XII.

					Degrees of freedom	Sums of squares	Mean square
Rows, columns, and p , v , i interactions					55	13011.82	
Rows and columns	...	...	...	...	22	12017.31	
p , v , i interactions	...	...	...	...	33	994.51	30.1
Error	...	...	...	...	76	4003.17	52.7

The p , v , i interactions have a lower variance than the error variance, the difference lying outside the lower 5 per cent. point. This significantly lower variance is apparently a chance effect, but it may be that there is some property of the lay-out which decreases the expectation of variance in these interactions.

In any case there is little doubt that the high order interactions of this experiment are negligible. The original analysis, by neglecting the fact that the rows and columns were not orthogonal with the treatments, and working on the crude treatment totals, produced apparent large interaction sums of squares which were in reality due to row and column effects. This in turn reduced the error sum of squares much below its true

value, giving an error variance of 29.09. As a consequence many of these interactions appeared to be significant, leading to conclusions of the type: "In the absence of nitrogen the response to phosphate only occurs if muriate of potash be absent also; in the presence of sulphate of ammonia the response to phosphate only occurs if either muriate of potash or salt is present; while in the presence of nitrate of soda the response to phosphate only occurs in the absence of salt" (*loc. cit.* pp. 581-2).

It will now be seen that the experiment, as it stands, is quite capable of giving a clear and unambiguous verdict on the main manurial effects, and that to obtain this verdict it is only necessary to carry out the first part of the analysis, combining the 33 non-orthogonal interaction degrees of freedom with the 76 error degrees of freedom. The extraction of the 33 interaction degrees of freedom has only confirmed the approximate procedure. But the experiment is not suitable for providing any estimate of the interactions between variety or phosphate and the non-phosphatic manures. An intolerable amount of labour would be required if it were desired to split up the 33 degrees of freedom further and examine individual interactions of this series, and although in this particular case the very low value of the sum of squares for the 33 degrees of freedom and a general examination of the values of the interaction constants (not given here) indicates that there is no significant interaction of this kind, yet in other cases it might well be that one or two of the principal interactions of the series might exist and be large enough to be significant. But the existence of a few such interactions, unless they were very large, would not appreciably affect the approximate error, owing to the number of degrees of freedom involved. On the other hand any definite verdict of significance or non-significance of these interactions themselves would be very troublesome.

The possibility of designing an experiment, similar to this one, but avoiding its disadvantages, must now be considered. Some sacrifice of the number of manurial treatments appears to be necessary. In the arrangement illustrated in Fig. 5 the manurial treatments 1-6 are arranged in the form of a 6×6 Latin square. Each row of this Latin square is subdivided into two strips receiving treatments A_1 and A_2 , and similarly each column is divided into two strips receiving treatments B_1 and B_2 . A_1 and A_2 , and B_1 and B_2 , are assigned at random within each pair of strips.

The analysis can be set out as in Table XIII. There are six separate and distinct errors appropriate to comparisons involving row strips, column strips, the Latin square plots, differences between main-plot

halves (two types), and cross differences between the main-plot quarters.

This analysis is of particular interest in that it shows up a defect, which has not yet been discussed, in the analysis of the sugar-beet experiment by the method of fitting constants. It has been tacitly assumed that the 76 degrees of freedom for error in that experiment are homogeneous, and that any set of treatment degrees of freedom, except the direct phos-

Table XIII.

Row strips		Column strips		Latin square	
	D.F.		D.F.		D.F.
Rows	5	Columns	5	Rows	5
$\{ A_1 v. A_2$	1	$\{ B_1 v. B_2$	1	Columns	5
Error	5	Error	5	Treatments	5
	—		—	Error	20
Row strips	11	Column strips	11	Total	35
Differences between large plot halves: $A_1 - A_2$		Differences between large plot halves: $B_1 - B_2$		Differences between large plot quarters: $A_1B_1 - A_1B_2 - A_2B_1 - A_2B_2$	
	D.F.		D.F.		D.F.
$\{ Deviations of row strips from rows$	6	$\{ Deviations of column strips from columns$	6	Interaction	
Interactions		Interactions		$A \times B$	1
$A \times 1 - 6$	5	$B \times 1 - 6$	5	Interactions	
Error	25	Error	25	$A \times B \times 1 - 6$	5
	—		—	Error	30
Total	36	Total	36	Total	36

phate and varietal effects, may be validly compared with them. For the new lay-out there are no less than 4 error sets of degrees of freedom corresponding to these 76 degrees of freedom and to the 24 additional error degrees of freedom introduced by reducing the number of treatments from 12 to 6. Although perhaps no great difference between the last three errors is to be expected, since they all depend on differences within the large plots, there is no question that the Latin square error will tend to be larger than the other three. Any analysis which confuses these errors will be of doubtful validity.

This point throws light on the question of the direct interaction of variety and phosphate. It seems probable that a specially accurate comparison should be available for this particular interaction, since it involves only differences of the type $PK - PJ - OK + OJ$, and plots receiving these four treatments occur in sets of four throughout the experiment. In the original analysis by Dr Wishart a special estimate of error was made for this interaction by comparing the variance of the 36 tetrad differences with the mean value of these differences, after compensating for effects of treatments 1-12 by applying adjustments to the individual

plot yields, equal in magnitude to the corresponding treatment means. The values obtained were as follows.

	Degrees of freedom	Sums of squares	Mean squares
Interaction of phosphate and varieties	1	234.60	234.60
Deviations of tetrad differences	35	547.30	15.64

This estimate of error variance is much below the general estimate for the 76 degrees of freedom, namely 52.7, and though the method of compensating for treatment effects introduces certain correlations which will tend to lower somewhat the estimate from tetrad differences, there is no doubt that the two errors are in fact significantly different. This difference offers a striking practical confirmation of the non-homogeneity of the 76 degrees of freedom for error used in the main analysis.

	B_2	B_1	B_1	B_2	B_2	B_1	B_2	B_1	B_1	B_2	B_2	B_1
A_1	1	1	3	3	2	2	6	6	4	4	5	5
A_2	1	1	3	3	2	2	6	6	4	4	5	5
A_1	5	5	4	4	1	1	3	3	2	2	6	6
A_2	5	5	4	4	1	1	3	3	2	2	6	6
A_2	3	3	5	5	6	6	2	2	1	1	4	4
A_1	3	3	5	5	6	6	2	2	1	1	4	4
A_1	6	6	1	1	5	5	4	4	3	3	2	2
A_2	6	6	1	1	5	5	4	4	3	3	2	2
A_2	4	4	2	2	3	3	5	5	6	6	1	1
A_1	4	4	2	2	3	3	5	5	6	6	1	1
A_2	2	2	6	6	4	4	1	1	5	5	3	3
A_1	2	2	6	6	4	4	1	1	5	5	3	3

Fig. 5.

The lay-out given in Fig. 5 suffers from the disadvantage that the comparisons of the treatments 1-6 involve the large plots of the 6×6 Latin square, so that the maximum efficiency is not obtained. By confounding interactions between A , B and 1-6 with the large plots of the Latin square, in place of the treatments 1-6, a gain in efficiency on the direct comparisons may be obtained, but this confounding is only possible with six sub-treatments when there are six sub-plots within each Latin

	B_2	B_1	B_2	B_1	B_1	B_2	B_2	B_1
A_1	2	1	1	2	3	4	3	4
	α		β		γ		δ	
A_2	4	3	3	4	1	2	1	2
A_2	1	2	4	3	4	3	2	1
	δ		α		β		γ	
A_1	3	4	2	1	2	1	4	3
A_2	3	4	2	1	2	1	4	3
	β		γ		δ		α	
A_1	1	2	4	3	4	3	2	1
A_1	4	3	3	4	1	2	1	2
	γ		δ		α		β	
A_2	2	1	1	2	3	4	3	4

Fig. 6.

square plot, necessitating three A (or B) treatments and 216 plots. Fig. 6 illustrates a lay-out of this type, but with four sub-treatments only, giving in all 64 plots. Each large plot of the Latin square consists of four plots receiving treatments 1-4. The conjunction of the treatments 1-4 and the A and B treatments within the plots of the Latin square is determined by a subsidiary Latin square:

Main plot	A_1B_1	A_1B_2	A_2B_1	A_2B_2
α	1	2	3	4
β	2	1	4	3
γ	3	4	1	2
δ	4	3	2	1

This has the effect of confounding the interaction αv , βv , γv , δv with the Latin square plots, while keeping the strips orthogonal with treatments 1-4. (This confounding of high-order interactions is dealt with more fully

in the next section). If treatments 1, 2, 3 and 4 represent the four combinations P_1Q_1 , P_2Q_2 , P_2Q_1 , P_1Q_2 respectively of two pairs of treatments P_1 , P_2 , and Q_1 , Q_2 , the analysis of Table XIV is obtained, the interactions $\alpha v.$ $\beta v.$ $\gamma v.$ δ being equivalent to $B \times Q$, $A \times P \times Q$ and $A \times B \times P$, etc.

Table XIV.

Row strips		Column strips		Latin square	
	D.F.		D.F.		D.F.
Rows	3	Columns	3	Rows	3
$A_1 v. A_2$	1	$B_1 v. B_2$	1	Columns	3
Error	3	Error	3	$B \times Q$	1
				$A \times P \times Q$	1
Row strips	7	Column strips	7	$A \times B \times P$	1
				Error	6
				Total	15
Plot halves, $A_1 - A_2$		Plot halves, $B_1 - B_2$		Plot quarters	
Deviations of row strips from rows	4	Deviations of column strips from columns	4	$A \times B$	1
$P \times Q$	1	Q	1	P	1
$B \times P$	1	$A \times P$	1	$A \times Q$	1
$A \times B \times Q$	1	$A \times B \times P \times Q$	1	$B \times P \times Q$	1
Error	9	Error	9	Error	12
				Total	16
Total	16	Total	16		

It should be noticed that the subsidiary Latin square given is the only one for which the interactions $\alpha v.$ $\beta v.$ $\gamma v.$ δ represent real physical effects. An alternative is to take 1-4 to represent P_1Q_1 , P_1Q_2 , P_2Q_1 and P_2Q_2 respectively, when $\alpha v.$ $\beta v.$ $\gamma v.$ δ will be equivalent to $A \times P$, $B \times Q$ and $A \times B \times P \times Q$. Larger experiments can be designed on similar lines. The 6×6 , 8×8 and 9×9 squares have been investigated, and present no theoretical difficulty.

VI. THE CONFOUNDING OF INTERACTIONS.

A type of confounding radically different to that considered in the last two sections occurs when the experiment is so arranged that degrees of freedom corresponding to high-order interactions are confounded with block differences. This type of confounding does not contribute directly to ease of execution, but it very greatly increases the accuracy of complex experiments.

It will be recalled(2) that a great gain in efficiency is attained by carrying out the examination of several effects in a single experiment. If, for example, it is desired to examine the manurial response of a crop to nitrogen, phosphate and potash, a single experiment made up of plots receiving all possible combinations of the three manures will be much more efficient, other things being equal, than three separate experiments

each of one-third the size. If, however, several rates of application for each manure are included the number of plots required for each complete replication becomes very large, and the size of blocks in a randomised block experiment must be correspondingly increased; the magnitude of soil differences of plots within the same block may then become unduly great, with the result that soil heterogeneity is not successfully eliminated by the blocks.

This difficulty can be overcome by sacrificing complete replication within each block. If, for instance, the plots of each completely replicated block are divided into a set of sub-blocks in such a manner that the comparison between sub-block totals corresponds to the comparison representing a set of high-order interactions, then the degrees of freedom corresponding to this set of interactions will be confounded with sub-block differences. Moreover each completely replicated block may be divided so that different high-order interactions are confounded, and thus some information is obtained on every degree of freedom, those that are confounded in one set of blocks being kept clear of block differences in other sets. In such a case it may well happen, if the accuracy of the comparisons not confounded is considerably increased, that even those that suffer some measure of confounding are more accurately determined than would be the case in a straightforward experiment.

As an example of complete confounding of a single degree of freedom corresponding to a high order interaction the type of experiment in which two levels of three different treatments, such as nitrogenous, phosphatic, and potassic fertilisers, are arranged in all possible combinations, eight in number, may be considered. There are seven degrees of freedom for treatments, which can be divided up into three for direct effects, three for first order interactions, and one for the second order interaction. The sum of squares corresponding to each single degree of freedom may be computed from the sum of half the plots less the sum of the other half; the direct nitrogen effect is measured by the difference of the sums of all the plots receiving nitrogen and those receiving no nitrogen, the interaction of nitrogen and potash from the difference of the sums of all the plots receiving both nitrogen and potash, or neither, and those receiving one or the other, the second order interaction from the difference of the sum of all the plots receiving all three manures, or one only, and the sum of those receiving two manures, or none. Bearing this in mind, it will be seen that the division of each complete replication into two blocks as in Table XV, types IA and IB, will leave every comparison free of block differences except the second order interaction, which will be completely confounded

with block differences. The full analysis of variance in a 32-plot experiment is given in Table XVI.

Table XV. *Block types in $2 \times 2 \times 2$ experiment.*

IA	IB	IIA	IIB	IIIA	IIIB	IV A	IV B
<i>N</i>	<i>O</i>	<i>N</i>	<i>O</i>	<i>N</i>	<i>O</i>	<i>P</i>	<i>O</i>
<i>P</i>	<i>NP</i>	<i>P</i>	<i>K</i>	<i>K</i>	<i>P</i>	<i>K</i>	<i>N</i>
<i>K</i>	<i>NK</i>	<i>NK</i>	<i>NP</i>	<i>NP</i>	<i>NK</i>	<i>NP</i>	<i>PK</i>
<i>NP</i> <i>K</i>	<i>PK</i>	<i>PK</i>	<i>NP</i> <i>K</i>	<i>PK</i>	<i>NP</i> <i>K</i>	<i>NK</i>	<i>NP</i> <i>K</i>

Table XVI.

	D.F.		D.F.
Second order interaction $N \times P \times K$	1	Direct effects	$\left\{ \begin{array}{l} N \\ P \\ K \end{array} \right.$ 1
Block pairs	3		1
Error	3		1
	—	First order interactions	$\left\{ \begin{array}{l} N \times P \\ N \times K \\ P \times K \end{array} \right.$ 1
Blocks	7		1
			1
		Blocks	7
		Error	18
		Total	31

The first part of the analysis assumes that the two types of block are actually grouped in pairs. In practice this part is not likely to be of any value; it is set out here for the sake of logical completeness only.

In this design all the information on the second order interaction (except the negligible amount derivable from the comparison of block totals) is sacrificed. The complete set of types in Table XV gives an alternative arrangement in which one-quarter of the information on each of the interaction degrees of freedom is sacrificed. The pairs of blocks IA and IB, IIA and IIB, IIIA and IIIB, IV A and IV B, each contain a complete replication, the pairs II, III and IV being split so as to confound the first order interactions $N \times P$, $N \times K$ and $P \times K$, respectively. The partition of the degrees of freedom will now be:

Direct effects	3
First order interactions	3
Second order interaction	1
Blocks	7
Error	17
Total	31

In this experiment the computation of the sums of squares to be allotted to the degrees of freedom which are partially confounded presents no difficulty. The second order interaction, for example, is simply computed from the blocks IIA, IIB, IIIA, IIIB, IV A, IV B, with which it is orthogonal, omitting entirely blocks IA and IB. The sum of squares

allotted to error can, as usual, be found by subtraction from the total sum of squares. It should be particularly noticed that this method of computation depends on the fact that the degree of freedom in question is *completely* confounded with the omitted pair of blocks, and orthogonal with the remaining blocks.

Yet another opportunity of obtaining information on degrees of freedom that at first sight appear to be confounded with block differences occurs when each sub-block contains a plot or plots receiving the same treatment as corresponding plots in the other sub-blocks, for then the differences between these plots furnish a measure of sub-block differences. If, for example, one block contained plots receiving treatments *A* and *B*, and another block contained plots receiving treatments *A* and *C*, it would be possible to make a comparison of *B* and *C* by comparing *B* with *A* in the first block and *C* with *A* in the second block.

As an example of this type of confounding, take the system of treatments, nitrogen and no nitrogen, applied early or late, and phosphate and no phosphate, eight combinations in all, of which the pair phosphate without nitrogen applied early or late, and the corresponding no phosphate pair, are identical. This system corresponds exactly to the system already considered, early and late application (of nitrogen) being substituted for potash. The experiment is not very efficient on the question of time of application, since only half the plots enter into this comparison, but this is unavoidable in experiments of this type: some increase of efficiency might be obtained by retaining only one of each pair of identical plots, but at the expense of balance on the phosphate and nitrogen comparisons.

If the plots of each replication are divided into two sub-blocks according to type I of the previous example we shall have block pairs of the type:

O_1	O_2
P_1	P_2
$N(L)$	$N(E)$
$PN(E)$	$PN(L)$

The five degrees of freedom for treatments may be partitioned as follows:

Phosphate	1
Nitrogen	1
Time of application	1
$P \times N$	1
$P \times T$	1

At first $P \times T$, which would ordinarily be computed from the sum of quantities of the type $N(E) + PN(L) - N(L) - PN(E)$, appears to be confounded with blocks, but, as explained above, a comparison can be

made by means of the other plots. The sum of squares is in fact (for complete fourfold replication)

$$\frac{1}{32} [S \{N(E) + PN(L) - N(L) - PN(E) - O_2 - P_2 + O_1 + P_1\}]^2.$$

This is orthogonal with the blocks and with all the other treatment degrees of freedom.

The above examples have purposely been chosen for their simplicity. The full enumeration of the different types of confounding in even the simpler types of lay-out is necessarily very complex and has never been fully investigated; but the examples given appear to embody the principles involved. Attention has been confined to cases where each full set of replicated plots is divided into two parts only, thus confounding a single degree of freedom. Extension to the case where there is division into more than two parts, with the consequent confounding of a set of degrees of freedom, presents no particular difficulty beyond that of choosing a suitable type of division.

The possibilities of confining the confounding to high-order interactions appear to be very limited. In an experiment consisting of three levels of three different treatments in all combinations, making 27 treatments in all, it is possible to confound two of the eight-second order interactions by splitting into three blocks of nine plots, and by varying the manner of splitting the whole 8 degrees of freedom may be partially confounded (as in the *NPK* example), but it is not possible to confound the whole 8 degrees of freedom by splitting into nine blocks of three plots. The best that can be done in this way is to confound degrees of freedom corresponding to two-second order and six first-order interactions.

An example of neat adaptation of the principle of confounding to a special purpose is afforded by the series of experiments on potatoes at Rothamsted begun in 1925 and ended in 1931. The first three experiments of this series have already been discussed in a previous paper in this *Journal*(3). The principle of confounding was first resorted to in the 1927 experiment, though at that time the possibility of gaining useful information on confounded degrees of freedom was not realised, and the 1927 experiment has a certain lack of symmetry which greatly complicates the full analysis. An outline of the numerical computation of the 1931 experiment is given here, as providing an excellent illustration of the simplicity of the analysis of apparently complex experiments when their design is satisfactory.

It will be recalled that the purpose of these experiments was to investigate the effect of nitrogenous and potassic fertilisers on potatoes.

In addition to the ordinary quantitative effects it was desired to compare three different sources of potash, namely sulphate of potash, muriate of potash, and low grade potash manure salt. The lay-out of the experiment, which is very similar to the 1927 experiment, is given in Fig. 7, together with the yields of the individual plots. In addition to the treatments shown the plots were split, one half receiving a dressing of superphosphate. There is no need to repeat this part of the analysis here, as it is quite straightforward, consisting in essence of an analysis of the differences of pairs of half-plots; as in this type of analysis no account is taken of blocks, it is unaffected by the confounding.

The full analysis of variance is given in Table XVII. The total sum of squares, that for blocks, and that for all treatment effects except the interactions involving both nitrogen and potash quality, are computed in the ordinary manner, except that the quality effect has been computed from the weighted means of the various qualities, giving double weight to the plots receiving a double dressing of potash. The sum of squares is in fact the sum of the squares of the deviations of the totals

$$S(S_1 + 2S_2), \quad S(M_1 + 2M_2), \quad S(P_1 + 2P_2),$$

from their mean, divided by 45, *i.e.* $9 \times (1^2 + 2^2)$. The interaction orthogonal to this pair of degrees of freedom is that given by the differences of

$$S(2S_1 - S_2), \quad S(2M_1 - M_2), \quad S(2P_1 - P_2),$$

the sum of the squares of the deviations being, as before, divided by 45. It is important to notice that a change in the method of measurement of a direct effect necessarily involves a corresponding change in the interaction.

Table XVII. *Analysis of variance (whole plots).*

	Degrees of freedom	Sum of squares	Mean square
Blocks	8	1,251,615	
Nitrogen	2	303,759	151,880
Potash quantity	2	10,291	5,146
Potash quality	2	17,374	8,687
Nitrogen \times potash quality	4	15,632	3,908
Potash quantity \times quality	2	31,294	15,647
Nitrogen \times potash quantity	8	56,797	7,100
Nitrogen \times quantity \times quality			
Error	52	410,462	7,894
Total	80	2,097,224	
Interactions: (a) for K_1	2	21,516	
(b) " K_1	2	10,247	
(a) " K_2	2	14,400	
(b) " K_2	2	10,634	
	8	56,797	

The three complete replications of the experiment are all divided differently into sub-blocks, and it would therefore at first sight appear that three pairs of degrees of freedom were confounded with blocks.

A			B			C		
3 1996	4 <i>P</i> 1638	5 <i>M</i> 1859	9 <i>M</i> 1978	2 2088	5 <i>P</i> 2197	1 2016	4 <i>M</i> 2398	6 <i>P</i> 2330
8 <i>P</i> 1818	7 <i>M</i> 1806	2 1972	1 1978	4 <i>S</i> 2185	6 <i>M</i> 2499	8 <i>M</i> 2535	3 2838	2 2382
6 <i>S</i> 2076	9 <i>S</i> 2115	1 2003	8 <i>S</i> 2460	3 2591	7 <i>P</i> 2655	9 <i>P</i> 2792	7 <i>S</i> 2649	5 <i>S</i> 2562
8 <i>S</i> 1687	7 <i>P</i> 1681	5 <i>S</i> 1822	5 <i>M</i> 2062	8 <i>M</i> 2304	2 2327	9 <i>S</i> 2384	3 2581	1 2122
6 <i>P</i> 1623	9 <i>M</i> 1841	4 <i>M</i> 1586	6 <i>S</i> 2012	4 <i>P</i> 1942	9 <i>P</i> 2368	5 <i>P</i> 2203	8 <i>P</i> 2345	4 <i>S</i> 1996
2 1651	1 1634	3 1665	7 <i>S</i> 1854	1 2064	3 2388	2 2195	6 <i>M</i> 2391	7 <i>M</i> 1685
4 <i>S</i> 1511	5 <i>P</i> 1687	9 <i>P</i> 1882	7 <i>M</i> 1877	9 <i>S</i> 2379	3 2462	4 <i>P</i> 2081	2 2288	6 <i>S</i> 2077
7 <i>S</i> 1562	3 1776	6 <i>M</i> 2080	4 <i>M</i> 1982	8 <i>P</i> 2082	6 <i>P</i> 2280	9 <i>M</i> 2296	8 <i>S</i> 2308	7 <i>P</i> 1652
8 <i>M</i> 1595	1 1501	2 1860	1 2096	5 <i>S</i> 2051	2 1889	3 2165	5 <i>M</i> 2007	1 1625
G			H			I		

Fig. 7.

Key to treatments.

Treatment	1	2	3	4	5	6	7	8	9
Nitrogen	0	1	2	0	1	2	0	1	2
Potash	0	0	0	1	1	1	2	2	2

S = sulphate of potash, *M* = muriate of potash, *P* = potash manure salt.

Actually, however, any one of these pairs can be constructed from the other two pairs, so that only 4 separate degrees of freedom are confounded.

The method of computation of the confounded degrees of freedom

utilises the principle that the interaction of a 3×3 table (4 degrees of freedom) can be split up into two pairs of degrees of freedom. The confounded degrees of freedom are those involving the interaction of nitrogen with potash quality and with potash quality and quantity. These are equivalent to the interaction of nitrogen with potash quality for the single dressing of potash, and the similar interaction for the double dressing. The 4 degrees of freedom for the single dressing can be split up into two sets involving comparisons of

(a) $S_1N_0 + M_1N_1 + P_1N_2$, $M_1N_0 + P_1N_1 + S_1N_2$, $P_1N_0 + S_1N_1 + M_1N_2$,
and

(b) $S_1N_0 + P_1N_1 + M_1N_2$, $P_1N_0 + M_1N_1 + S_1N_2$, $M_1N_0 + S_1N_1 + P_1N_2$.

It will be seen that the first pair of comparisons is orthogonal with blocks, and consequently the sum of squares may be computed in the ordinary manner. The second pair consists of the comparison of all the single potash plots in blocks B, F and G with those in A, E and I and in C, D and H. To eliminate block effects the other plots in the block are utilised as already explained, the comparison being made between quantities of the type

$$S(2K_1 - K_2 - K_0),$$

the summations being taken over the three sets of blocks. The numerical values are

Blocks	$S(2K_1 - K_2 - K_0)$
B, F, G	+ 260
A, E, I	- 1841
C, D, H	- 888

The sum of the squares of the deviations of these numbers from their mean, divided by 54, *i.e.* $9 \times (2^2 + 1^2 + 1^2)$, gives the required sum of squares. For the double dressing of potash the computation is similar, but here the opposite pair of interactions is confounded.

It is important to notice that the validity of the above process depends on the fact that after compensation is made for block differences each pair of confounded degrees of freedom is not only orthogonal with blocks, but also with all treatment degrees of freedom, including the other confounded pair. A rigorous proof of the whole procedure can be made by fitting constants.

This orthogonal property depends on the symmetry of the experiment. It does not hold for the 1927 experiment, and consequently the above method of computation breaks down. A full analysis can best be made by fitting constants for the blocks and confounded interactions,

and solving the resultant equations, a somewhat lengthy process; alternatively the confounded degrees of freedom can be combined with the error degrees of freedom, on the assumption that the effects if any are small, and consequently unlikely seriously to increase the estimate of error above its true value. This latter process was the one actually adopted in the original analysis, and is justified *a posteriori* in every other experiment of the series, but it is interesting to note that full analysis of the 1927 experiment revealed a very strong interaction between nitrogen and potash quality, this being due to the low yields of potash manure salt in conjunction with nitrogen. This effect can easily be seen if the treatment effects are judged from totals of deviations from block means instead of from crude totals; it accounts for the definitely significant differences between the different kinds of potash in this year. The effect is entirely absent in other years.

One further point should be mentioned in connection with the computation of confounded experiments. The differences between the crude treatment means corresponding to confounded degrees of freedom are affected by block differences. If the degrees of freedom are completely confounded no comparison is possible on the basis of the ordinary error; if the degrees of freedom are partially confounded comparison is still possible, but allowance must first be made for block differences, and it must be remembered that even then such comparisons are subject to higher error than the rest. Inasmuch as the analysis of variance provides precise tests of significance there is no need to evaluate special errors, but it is as well in exhibiting the results to avoid giving tables which involve completely confounded degrees of freedom. If it is desired to show an effect corresponding to a partially confounded degree of freedom the treatment means must be corrected. It must be remembered that the corrections cannot be deduced directly from the crude block means, since these means themselves contain differences due to the partially confounded degrees of freedom. It is therefore easiest to build up a table from the various treatment and interaction differences which have been determined by the analysis.

The 1931 potato experiment, of which the analysis has just been given, will serve as an example of the process. The estimates of the deviations from the mean yield produced by the nitrogen and potash in all combinations are one-ninth the deviations of the totals of these nine treatment combinations; the value for K_1N_0 , for example, is -- 148.2. The potash quality effects at the single level of potash are measured by one-ninth the deviations of the totals of the three qualities at this potash

level from their mean, and a similar process serves for the double level of potash. The only remaining effects are the interactions of nitrogen with potash quality at the two levels of potash. At the single level of potash the (a) interactions are orthogonal with blocks, and the appropriate measures of the effects are therefore one-ninth the deviations of the totals of $S_1N_0 + M_1N_1 + P_1N_2$ and the two corresponding quantities, the first of these being -58.4 . The (b) interactions are not orthogonal with blocks, and the appropriate measures are therefore one-eighteenth the deviations of the totals $S(2K_1 - K_2 - K_0)$ over the appropriate blocks. The first is $+60.2$. It will be noted that all these quantities can be immediately written down, since the appropriate totals have already been obtained in the analysis of variance. The estimation of a constant multiple of a single plot yield, in this case nine times, will further simplify the numerical work.

It remains to build up the final yield table. The entry for S_1N_0 , for example, on a single plot basis, will be given by

$$2072.6 - 148.2 - 9.7 - 58.4 + 60.2 = 1916.5.$$

In conclusion it should be emphasised that it is by no means always necessary to construct tables of this type. In cases where the partially confounded degrees of freedom are not significant it usually suffices to exhibit the main unconfounded effects.

VIII. SUMMARY.

The principle of orthogonality in replicated experiments is discussed and the dangers of non-orthogonality emphasised. The modifications necessary in the ordinary procedure of the analysis of variance when applied to non-orthogonal data are developed, attention being paid to the shorter methods, applicable in certain cases, by which the heavy labour of computation necessary in the general method of fitting constants may be avoided.

Certain modifications in the design of replicated experiments, usually designated by the term confounding, are explained. The different types of confounding are discussed, together with their uses, and the appropriate methods of analysis are set out. The methods are applied to the analysis of an experiment on sugar beet (where a previous incorrect analysis is corrected) and an experiment on potatoes.

In conclusion I desire to express my thanks to Dr R. A. Fisher for his helpful advice and criticism.

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(Received November 14th, 1932.)

THE ANALYSIS OF REPLICATED EXPERIMENTS WHEN THE FIELD RESULTS ARE INCOMPLETE

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1. *Introduction.*—The principles of randomization and replication, recently introduced into the design of agricultural field trials, have greatly increased their accuracy, and have rendered possible valid tests of significance and estimates of the experimental errors. But as in all experimental work, it sometimes happens that accidental causes upset the original design, so that the methods of analysis which are ordinarily appropriate require modification. In general, replicated field trials are so arranged that the mean yield of all the plots receiving a given treatment provides the best estimate of the effect of that treatment, free from any extraneous effects, such as fertility differences, which are allowed for in the design. Thus in a randomized block experiment, in which every treatment occurs once in each block, an increase in the fertility of any one block will increase all the treatment means equally, and therefore will not affect comparisons between them. Fertility differences within blocks, on the other hand, will affect comparisons between treatment means, but variation due to this cause also increases the estimate of error and, if the principle of randomization is followed, differences merely due to fertility differences within the blocks will not in general be regarded as providing evidence of real treatment effects. In such an experimental design, where changes in block fertility do not affect differences between treatment means, and conversely changes in treatment effects do not affect differences between block means, blocks and treatments are said to be orthogonal. This property is an extremely valuable one, since not only are the treatment means the best estimates of the treatment effects, but the whole procedure of the analysis of variance, by which an estimate of error may be made, is very simple. When more than two sets of effects are present orthogonality can still be secured, as in a Latin square, where rows, columns, and treatments are all orthogonal to one another, any change in a general fertility of one row, for instance, affecting all the column and treatment means equally. Treatments themselves may also be arranged in orthogonal sets, as when three levels of nitrogen are applied in conjunction with three levels of potash, making nine treatments in all. Such an arrangement provides information not only on the response to nitrogen and to potash separately, but also on the differences in these responses in the presence of different quantities of the other manure. Moreover, orthogonality enables the various effects to be separated in the analysis of variance without difficulty.

If the yields of some plots are lost, or are unreliable, the orthogonality of the original design disappears. Thus in a randomized block experiment with one plot missing, an increase in the fertility of the block containing that plot will affect all treatment means except the one

containing the missing plot, and if therefore there is any real difference in the fertility of the different blocks a bias will be introduced into the treatment means, so that their differences are no longer the best estimates of the treatment effects. Nor can the procedure of the analysis of variance appropriate to orthogonal experiments be applied directly to non-orthogonal data. In another paper [1] I have discussed the analysis of non-orthogonal experiments in general, but the case where a few values are missing from an otherwise orthogonal experiment is best dealt with by the special method to be described in this paper.

The problem of analysis may be divided into two parts, the estimation of the magnitude of the effects the experiment was designed to test, and the provision of appropriate tests of significance and estimates of error. The whole problem can be dealt with most successfully by estimating the yields of the missing plots. Such estimates, if properly chosen, when included in the treatment means make these latter efficient estimates of the treatment differences, free from any bias due to other effects such as fertility differences which the experiment was designed to eliminate. After estimating the yields of the missing plots, the ordinary procedure of the analysis of variance suitable to orthogonal experiments may be followed, and though not strictly correct it will be shown that it gives quite satisfactory results in ordinary cases provided the number of degrees of freedom for error is reduced by the number of plots missing. The significance of the results is always slightly exaggerated, though quite negligibly so when only a few values are missing.

The formulae appropriate in the case of a single plot of a randomized block or Latin square have already been given by Miss Allan and Dr. Wishart [2], but no attempt was made to estimate the errors of the treatment differences, and it was assumed that the ordinary procedure of the analysis of variance, if carried out on all the yields, including the estimated yield, was strictly valid when the number of degrees of freedom allotted to error was reduced by one.

The question of the retention or rejection of values which are for some reason considered unreliable may be briefly considered here. In general the mere fact that a value is outstanding does not furnish adequate grounds for its rejection, since it is probable that the causes which produced this outstanding value have also disturbed the other values, though to a lesser extent. The outstanding value must therefore be included in the analysis so that it makes its fair contribution to error. If the magnitude of the error so obtained is so great as to prevent any definite conclusions being drawn, this verdict of non-significance must be accepted. It cannot be too strongly emphasized that the rejection of values, simply because they differ from the rest, is incompatible with any subsequent test of significance and entirely invalidates such tests. On the other hand, if there is sound external evidence for believing a value to be unreliable, such as information that one particular plot and only that plot has suffered from the depredations of some pest, or that previous to the experiment a particular plot was the site of a heap of dung, then rejection may be resorted to. In certain cases when a value is reported to be unreliable owing to some external cause, it is doubtful

if the cause is such as to produce any material difference. The experiment itself may legitimately be used to furnish evidence on this point, the reduction in the error sum of squares due to the rejection of the doubtful value being tested for significance against the new error sum of squares.

2. *Method of obtaining missing values.*—The procedure of fitting constants followed by Miss Allan and Dr. Wishart in establishing their formulae becomes involved when applied to complex experiments, and to cases where more than one plot is missing. It was suggested to me by Dr. R. A. Fisher that a much simpler solution might be effected by minimizing the error variance obtained when unknowns are substituted for the missing yields. The validity of this process may be proved rigorously as follows. For simplicity the case of a double classification, e.g. blocks and treatments, is considered, though the proof is perfectly general.

TABLE I

Treatments.	1	2	3	. .	q
1	y_{11}	y_{12}	y_{13}	. .	y_{1q}
2	y_{21}	y_{22}	y_{23}	. .	y_{2q}
..
p	y_{p1}	y_{p2}	y_{p3}	. .	y_{pq}

Let Table I represent the experimental yields. If these yields are assumed to be made up of additive functions of the blocks and treatments, and an error term, so that

$$y_{rs} = k + t_r + b_s + x_{rs},$$

then the analysis of variance may be regarded as the process of finding the most likely values of the constants k , t_1 , t_2, \dots, t_p , b_1 , b_2, \dots, b_q , and the errors associated with them; that is the values such that $S(x_{rs}^2)$ is minimum [3].

In the case where all the yields are known the solution is very simple, being given by

$$\hat{k} = \bar{y}, \quad \hat{t}_r = \frac{1}{q} \sum_1^q y_{rs}, \quad \hat{b}_s = \frac{1}{p} \sum_1^p y_{rs}. \quad (A)$$

In general, however, it is necessary to minimize the function

$$F = S(y_{rs} - k - t_r - b_s)^2, \quad (B)$$

the summation being taken over all existing plot yields.

Now suppose that various plot yields are missing. Assuming for the moment that the most likely values \hat{k} , \hat{t}_1 , $\hat{t}_2, \dots, \hat{b}_1$, \hat{b}_2, \dots of the constants have been found by the above process, put

$$Y_{uv} = \hat{k} + \hat{t}_u + \hat{b}_v \quad (C)$$

for each missing plot. Then Y_{uv} may be taken as an estimate of the yield of the uv th missing plot. If we complete the table of plot yields with these estimates and then perform an ordinary analysis of variance, we shall in fact minimize

$$F' = S(y_{rs} - k - t_r - b_s)^2 + S(Y_{uv} - k - t_u - b_v)^2,$$

where the first summation is taken over all the existing plots, and the

second over all those of which the yields are missing; this function is the part of the sum of squares allotted to error in the analysis of variance. The second sum of squares is clearly zero by virtue of (C) when the first sum of squares is minimum, i.e. when the most likely values of $k, t_1, t_2, \dots, b_1, b_2, \dots$ are obtained. The second sum of squares cannot be negative, and consequently the whole function is now a minimum. But since F' represents the sum of squares over the whole experiment it is minimum for the values of $k, t_1, \dots, b_1, \dots$, given by (A). We may, therefore, instead of minimizing the function F , thus determining directly $\hat{k}, \hat{t}_1, \dots, \hat{b}_1, \dots$, minimize F' , using this to determine Y_{uv} , afterwards obtaining $\hat{k}, \hat{t}_1, \dots, \hat{b}_1, \dots$ from (A).

3. *General formula for a single missing plot.*—Suppose that there is a multiple classification of the l th order, so that every plot is a member of l classes. Let p, q, r, \dots be the number of classes in each group, and let n be the number of plots. Thus in a 5×5 Latin square $l = 3$, $p = q = r = 5$, and $n = 25$. Let the sum of all the known yields in the class of the first set of classes containing the missing plot be P , that of the second set be Q , and so on, and let T be the total of all the known yields.

Writing x for the yield of the missing plot and following the ordinary methods of the analysis of variance, the following values for the terms containing x in the sums of squares are obtained:

$$\begin{array}{rcl} \text{1st classification} & \dots & \frac{p}{n}(P+x)^2 - \frac{1}{n}(T+x)^2. \\ \text{2nd classification} & \dots & \frac{q}{n}(Q+x)^2 - \frac{1}{n}(T+x)^2. \\ & \dots & \dots \\ \text{Total} & x^2 - & \frac{1}{n}(T+x)^2. \end{array}$$

Hence the residual (error) sum of squares is

$$x^2 - \frac{p}{n}(P+x)^2 - \frac{q}{n}(Q+x)^2 - \dots + \frac{l-1}{n}(T+x)^2.$$

Minimizing this, we obtain the equation to determine x ,

$$x\{(n+l-1)-(p+q+r+\dots)\} = (pP+qQ+rR+\dots)-(l-1)T.$$

In the case of a randomized block experiment, with p treatments, each occurring in q blocks, $n = pq$ and $l = 2$. The sums of the yields of all plots receiving the same treatment and in the same block as the missing plot are P and Q respectively, T being the total yield, and the formula for the missing yield becomes

$$x = \frac{pP+qQ-T}{(p-1)(q-1)}.$$

In the case of a Latin square, with p treatments, $p = q = r$, $n = p^2$, and $l = 3$. If P_r, P_c , and P_t represent the totals of the known yields of the row, column, and treatment from which the plot is missing, the formula becomes

$$x = \frac{p(P_r+P_c+P_t)-2T}{(p-1)(p-2)}.$$

These formulae will be found to agree with those given by Miss Allan and Dr. Wishart [2], save that the plus sign in their formula for a Latin square should be minus.

It should be noted that the general formula deduced above does not include all possible types of classification. In cases where it is not applicable the method of minimizing the error term directly must be followed.

Examples of the application of the formulae for randomized blocks and Latin squares have been given by Miss Allan and Dr. Wishart. There is no need to include any further examples of a single missing plot here, since the use of the formulae is illustrated in the next section in an example where several plots are missing, and again in section 7.

4. *Procedure when several plots are missing.*—In this case the part of the sum of squares allotted to error will be a quadratic function of the yields x, y, z, \dots of all the unknown plots. On minimizing this function, we shall obtain a set of simultaneous linear equations in x, y, z, \dots .

If P_x is the total of all the known yields in that one of the first set of classes which contains x , P_{yz} the similar total for the class which contains y and z , etc., it being assumed that these two classes contain only these unknown plots and no others, the quadratic function is of the type

$$x^2 + y^2 + z^2 + \dots - \frac{p}{n} \{ (P_x + x)^2 + (P_{yz} + y + z)^2 + \dots \} \\ - \frac{q}{n} \{ (Q_x + x)^2 + (Q_y + y)^2 + (Q_z + z)^2 + \dots \} - \dots + \frac{l-1}{n} (T + x + y + z + \dots)^2.$$

It will be seen that if two unknown plots are members of one class there is a radical difference of form.

The first three linear equations in the case given are

$$\begin{aligned} x(n+l-1-p-q-\dots) + y(l-1) + z(l-1) + \dots \\ = pP_x + qQ_x + \dots - (l-1)T, \\ x(l-1) + y(n+l-1-p-q-\dots) + z(l-1-p) + \dots \\ = pP_{yz} + qQ_y + \dots - (l-1)T, \\ x(l-1) + y(l-1-p) + z(n+l-1-p-q-\dots) + \dots \\ = pP_{yz} + qQ_z + \dots - (l-1)T. \end{aligned}$$

These equations are most easily solved by iterative methods, but in practice there is no need to write them down in the simpler type of experiment, since repeated applications of the formula for a single missing plot, substituting approximate values for all other missing plots, is clearly identical with the ordinary iterative process. The solution converges very rapidly and under ordinary circumstances the second approximation is amply accurate. The details of the numerical calculation are best illustrated by an example.

Example.—Table 2 gives a set of measurements on the intensity of infection of potato tubers inoculated with *Phytophthora Erythrosetptica* under various manurial treatments.

TABLE 2

Treat- ments	Blocks										Total
	1	2	3	4	5	6	7	8	9	10	
O	3.55	2.29	<i>b</i>	2.00	3.34	3.83	3.86	3.50	2.23	2.91	27.51 + <i>b</i>
N	2.30	4.03	2.54	2.82	3.29	2.93	<i>f</i>	2.55	2.20	2.30	24.96 + <i>f</i>
K	3.96	3.02	3.40	2.50	2.94	3.70	3.82	2.54	3.18	3.69	33.41
P	2.99	3.99	2.90	3.97	4.49	4.70	3.86	<i>h</i>	3.50	3.59	33.99 + <i>h</i>
NK	<i>a</i>	3.07	3.49	1.07	3.99	3.48	3.80	3.68	3.24	2.70	28.52 + <i>a</i>
NP	2.36	3.47	2.64	3.17	3.26	3.28	<i>g</i>	<i>i</i>	3.07	3.12	24.37 + <i>g</i> + <i>i</i>
KP	2.16	2.34	1.96	2.60	3.77	<i>d</i>	3.20	3.47	2.67	3.33	25.50 + <i>d</i>
NKP	3.16	2.52	2.39	3.68	<i>c</i>	<i>e</i>	3.85	3.36	2.50	4.13	25.59 + <i>c</i> + <i>e</i>
Total	20.48 + <i>a</i>	25.33	19.38 + <i>b</i>	21.81	25.08 + <i>c</i>	21.92 + <i>d</i> + <i>e</i>	22.39 + <i>f</i> + <i>g</i>	19.10 + <i>h</i> + <i>i</i>	22.59	25.77	223.85 + <i>a</i> + <i>b</i> + <i>c</i> + <i>d</i> + <i>e</i> + <i>f</i> + <i>g</i> + <i>h</i> + <i>i</i> .

Nine values were missing, indicated by the letters *a, b, c, ..., i*. In order to start the process of approximation all the missing values may be assumed to be equal to the mean 3.15. (In cases where the effect of blocks or treatments is very marked it is better to start with the block or treatment means instead of the general mean.) The value of the total, 223.85, must be increased by eight times the value of the mean in order to give an approximate total, 249.05, with only one plot missing. The first approximation for *a* is then given by

$$(10 \times 20.48 + 8 \times 28.52 - 249.05)/63.$$

This can be very rapidly computed on a calculating machine, multiplying by the reciprocal of 63, 0.01587, in order to avoid division. If a machine is not available a slide-rule will give all necessary accuracy. The value of 2.92 is thus obtained. The value of *b* may be computed in the same way, without troubling to alter the approximate total 249.05, which may be kept unchanged throughout the first approximation. When obtaining *c* the treatment total 25.59 must be increased by 3.15 to allow for the other missing plot *e*. In evaluating *e* the same treatment total must be increased by the value of *c*, the value given by the first approximation, 3.67, being taken in preference to the original mean value. The same procedure is followed throughout until a complete set of values is obtained. The new total, 254.10, can now be utilized, being decreased by the first approximation to each plot in turn. The second approximation for *a* is therefore given by

$$\{10 \times 20.48 + 8 \times 28.52 - (254.10 - 2.92)\}/63.$$

The complete set of values for both first and second approximations is:

	<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	<i>e</i>	<i>f</i>	<i>g</i>	<i>h</i>	<i>i</i>
1st approximation:	2.92	2.62	3.67	3.26	3.76	3.27	3.61	3.89	3.25
2nd approximation:	2.88	2.58	3.73	3.33	3.76	3.32	3.61	3.89	3.22

The second approximation is accurate to within 0.01. The amended treatment means are found to be:

O	N	P	K	NK	NP	KP	NKP
3.009	2.828	3.341	3.788	3.140	3.120	2.884	3.309

and these provide efficient estimates of the treatment effects, whereas the original treatment means were affected by block differences, the

treatment NKP, for example, having too low a mean, 3.199, because of the missing values in blocks 5 and 6, which have high values throughout.

In conclusion, it will be instructive to derive the equations for determining the missing values, in order to illustrate the application of the direct method to numerical data. The derivation of the equations *ab initio* is always the safest procedure in complex experiments where there may be some doubt as to the correct formula for a single missing plot.

In this example the error sum of squares is obtained by subtracting the sums of squares for blocks and treatments from the total sum of squares. Omitting numerical terms, i.e. terms not containing any letter, these sums of squares are as follows:

$$\text{Total:} \quad a^2 + b^2 + \dots + i^2 - \frac{1}{80}(223.85 + a + b + \dots + i)^2.$$

Blocks:

$$\frac{1}{8}\{(20.48 + a)^2 + (19.38 + b)^2 + \dots + (19.10 + h + i)^2\} \\ - \frac{1}{80}(223.85 + a + b + \dots + i)^2.$$

Treatments:

$$\frac{1}{10}\{(27.51 + b)^2 + (24.96 + f)^2 + \dots + (25.59 + c + e)^2\} \\ - \frac{1}{80}(223.85 + a + b + \dots + i)^2.$$

The equation with d as leading term, for example, can now be written down by differentiating these three quantities with respect to d , and subtracting the last two differentials from the first. On performing this operation, and dividing by 2, we obtain

$$d - \frac{1}{8}(21.92 + d + e) - \frac{1}{10}(25.50 + d) + \frac{1}{80}(223.85 + a + b + \dots + i) = 0.$$

The other equations may be obtained likewise. On multiplication by 80, and simplification, we have, finally,

+63a	+1b	+1c	+1d	+1e	+1f	+1g	+1h	+1i	= 209.11,
+1	+63	+1	+1	+1	+1	+1	+1	+1	= 190.03,
+1	+1	+63	+1	-7	+1	+1	+1	+1	= 231.67,
+1	+1	+1	+63	-9	+1	+1	+1	+1	= 199.35,
+1	+1	-7	-9	+63	+1	+1	+1	+1	= 200.07,
+1	+1	+1	+1	+1	+63	-9	+1	+1	= 199.73,
+1	+1	+1	+1	+1	-9	+63	+1	-7	= 195.01,
+1	+1	+1	+1	+1	+1	+1	+63	-9	= 239.07,
+1	+1	+1	+1	+1	+1	-7	-9	+63	= 162.11.

The solution of these equations may be effected by iterative methods similar to those used in conjunction with the formula for a single missing plot.

5. *Tests of significance.*—If values are found for the missing plots by the method already explained, and an analysis of variance made on the completed set of yields, the residual sum of squares will be the same as the residual sum of squares obtained when a direct fitting of constants is made, in virtue of the theory given in section 2. The number of degrees of freedom corresponding to this sum of squares will be the number attributable to the residual sum of squares in a similar but complete experiment less the number of missing plots, for the number of fitted constants is the same as in the complete experiment and the

number of independent values (yields) less by the number missing. In so far as the residual variance is concerned, therefore, it is only necessary to reduce the number of degrees of freedom in the analysis of the completed set of values by the number of missing plots.

The variance ascribable to treatments (or any other classification) requires more careful consideration. In general, in non-orthogonal experiments the significance of any set of fitted constants may be tested by finding the further reduction in the sum of squares due to the fitting of these constants simultaneously with constants corresponding to all the other classifications [1]. In certain circumstances it is permissible to neglect some of the classifications (such as treatment interactions) but this point need not concern us here. Therefore, in order to test the significance of treatments in a randomized block experiment with missing plots it is necessary to find the difference of the sum of squares removed by the fitting of constants corresponding to both blocks and treatments and that removed by constants for blocks only.

The sum of squares removed by block and treatment constants can be found by calculating the total sum of squares of the original yields without the missing values (less the correction for the mean) and deducting the residual sum of squares found by analysis of the completed experiment, which, as mentioned above, is equivalent to the residual sum of squares obtained with a direct fitting of the constants. The sum of squares removed by blocks only is obtained directly from the original block totals, following the procedure of the analysis of variance with unequal numbers in the different classes [4, § 44]. The various steps will best be made clear by an example.

Example.—The ordinary analysis of variance of the completed set of values of the experiment on potatoes already described is given in Table 3, and the correct value for the treatment variance is obtained in Table 4. In this latter table the total sum of squares is the sum of the squares of the deviations of all the values in Table 1 from their mean, and the error sum of squares comes from Table 3, giving the blocks and treatments sum of squares; the sum of squares for blocks only comes from the block totals of Table 1, each total after squaring being divided by the number of plots in that block. The difference of these last two quantities gives the proper sum of squares by which treatments may be tested.

The correct mean square for treatments is seen to be less than the mean square obtained by the analysis of the completed set of values. That this is always so can be shown by the following line of reasoning.

TABLE 3. *Analysis of Completed Values*

	Degrees of freedom	Sum of squares	Mean square	<i>z</i>
Blocks	9	9·7176	1·0797	0·596
Treatments	7	6·5812	0·9402	0·528
Error	54	17·6902	0·3276	
Total	70	33·9890		

TABLE 4. *Analysis of Original Values*

	Degrees of freedom	Sum of squares	Mean square	<i>z</i>
Total . . .	70	32.1012	..	..
Error . . .	54	17.6902	0.3276	..
Blocks and treatments	16	14.4110	..	..
Blocks only . .	9	8.5690	..	..
Difference . .	7	5.8420	0.8346	0.467

For simplicity, the case of a randomized block experiment is chosen, as in section 2.

An analysis of variance may be made with letters for the unknown yields, ignoring the classification to be tested, i.e. in the case of a randomized block experiment an analysis for blocks only. It is clear that an auxiliary set of values may be obtained which will minimize the residual sum of squares of this analysis. In the notation of section 2 the auxiliary set of values is such that

$$S(y_{rs} - k - b_s)^2$$

is as a minimum, the summation being taken over all existing plots, when k and b_s have the values k' and b'_s given by

$$k' = \frac{1}{pq} \sum_1^{pq} y_{rs}, \quad b'_s = \frac{1}{p} \sum_1^n y_{rs},$$

where the summations now include the missing plots, the auxiliary values being taken.

The analysis of the two completed sets of yields may be set out as follows, the letters denoting the sums of squares.

Ordinary values		Auxiliary values	
Blocks	B_o	Blocks	B_a
Treatments	T_o	Residuals	E_a
Error	E_o	Total	S_a
Total	S_o		

If the sum of squares of the deviations of the existing yields from their mean is denoted by S , the reduction in this sum of squares due to fitting block and treatment constants is $S - E_o$, and the reduction due to fitting constants for blocks only is $S - E_a$, in virtue of the relations established in section 2. The difference between these two quantities, which is the correct sum of squares for testing treatments, is therefore $E_a - E_o$, or

$$T_o - S_o + B_o + S_a - B_a$$

Now $S_o - B_o$ is clearly equal to $S(y_{rs} - \hat{k} - \hat{b}_s)^2$, the summation being taken over all the plots with the ordinary values of the missing plots, and $S_a - B_a$ is equal to $S(y_{rs} - k' - b'_s)^2$, the auxiliary values of the missing plots being taken, so that the terms corresponding to the missing plots are zero in the second summation. The values of k' and b'_s are such that the second expression is a minimum, and therefore $S(y_{rs} - \hat{k} - \hat{b}_s)^2$ must

be greater than $S(y_{rs} - k' - b'_i)^2$. Hence the sum of squares due to treatments in the analysis of the completed ordinary set of values (T_o) must be greater than the correct sum of squares by which treatments may be tested. The same argument holds, with the addition of extra sets of constants, for more complex classifications.

In consequence of this result the significance of any effect is always slightly exaggerated in the analysis of variance of the completed set of values, when this analysis is made on the ordinary lines except for the reduction of the number of degrees of freedom for error by the number of missing plots. If, therefore, an effect is found to be not significant in this analysis there is no need to make any further test. On the other hand, if an effect is found to be significant there is theoretically need for further analysis. In practice, however, the difference between the correct and approximate sum of squares is never likely to be great enough to affect the tests of significance seriously, except, perhaps, in cases where a large proportion of the plots is missing.

In the case of a randomized block experiment the amount by which the treatment sum of squares should be reduced is capable of direct expression by a simple formula. The estimated yield of the missing plot of a block containing only one such plot will be denoted by a , the block total excluding this plot by Q_a , and including this plot by V_a . For a block containing two missing plots the corresponding quantities are taken as b_1, b_2, Q_b , and V_b , \sum_1, \sum_2 , etc., denote summation over all blocks

containing one, two, or more missing plots. As before p represents the number of treatments.

Omitting terms not containing a, b_1, b_2 , etc., we have

$$S_o - B_o = \sum_1 \left\{ a^2 - \frac{1}{p} (Q_a + a)^2 \right\} + \sum_2 \left\{ b_1^2 + b_2^2 - \frac{1}{p} (Q_b + b_1 + b_2)^2 \right\} + \dots$$

Since, as pointed out above, the auxiliary values of the missing plots in the case of a randomized block experiment are merely the block means, the value of $S_a - B_a$ may be immediately obtained by substitution of $Q_a/(p-1)$ for a , $Q_b/(p-2)$ for b_1 and b_2 , etc., in the above expression. This gives

$$S_a - B_a = - \sum_1 \frac{1}{p-1} Q_a^2 - \sum_2 \frac{1}{p-2} Q_b^2 - \sum_3 \frac{1}{p-3} Q_c^2, \dots$$

Thus

$$\begin{aligned} S_o - B_o - S_a + B_a &= \sum_1 \left\{ \frac{p-1}{p} a^2 - \frac{2}{p} a Q_a + \frac{1}{p(p-1)} Q_a^2 \right\} \\ &+ \sum_2 \left\{ b_1^2 + b_2^2 - \frac{1}{p} (b_1 + b_2)^2 - \frac{2}{p} (b_1 + b_2) Q_b + \frac{2}{p(p-2)} Q_b^2 \right\} \\ &+ \sum_3 \left\{ c_1^2 + c_2^2 + c_3^2 - \frac{1}{p} (c_1 + c_2 + c_3)^2 - \frac{2}{p} (c_1 + c_2 + c_3) Q_c + \frac{3}{p(p-3)} Q_c^2 \right\} \\ &+ \dots, \end{aligned}$$

and this, by the identity between the n quantities $\alpha, \beta, \gamma, \dots$

$(\alpha + \beta + \gamma + \dots)^2 + n(\alpha^2 + \beta^2 + \gamma^2 + \dots) \equiv (\alpha - \beta)^2 + (\alpha - \gamma)^2 + (\beta - \gamma)^2 + \dots$,
and the substitution of V_a for $Q_a + a$, etc., reduces to

$$\begin{aligned} & \frac{1}{p(p-1)} \sum_1 (V_a - pa)^2 \\ & + \frac{1}{2p(p-2)} \sum_2 \{2V_b - p(b_1 + b_2)\}^2 + \frac{1}{3p(p-3)} \sum_3 \{3V_c - p(c_1 + c_2 + c_3)\}^2 + \dots \\ & + \frac{1}{2} \sum_2 (b_1 - b_2)^2 + \frac{1}{3} \sum_3 \{(c_1 - c_2)^2 + (c_1 - c_3)^2 + (c_2 - c_3)^2\} + \dots, \end{aligned}$$

which is the expression required. This formula clearly shows that the difference is never likely to be large.

Applying the formula to the potato experiment already worked out, the difference is found to be 0.7391, which agrees with the result previously obtained. The difference for the sum of squares due to blocks in the same experiment is 1.6630, giving a corrected mean square of 0.8950 ($z = 0.503$). Neither of these corrections seriously alters the significance of the results. If only a single plot is missing the differences are likely to be quite trivial.

The strict analysis of more complex classifications is not so simple, for the reason that the reduction in the sum of squares due to the fitting of all sets of constants other than the one under test cannot be directly computed. In a Latin square, for example, in order to test the significance of the treatments it is necessary to compute the reduction in the sum of squares due to fitting constants for rows and columns only; this can best be done by finding an auxiliary set of values for the missing plots, neglecting the treatment classification, i.e. by utilizing the formula for randomized blocks, taking rows and columns in place of blocks and treatments. For a Latin square the difference between the sums of squares does not lend itself to simple expression by means of a formula except in the case when one plot is missing. In the notation of section 2 the difference then is

$$\frac{1}{(p-1)^2(p-2)} \{(p-1)P_t + P_r + P_c - T\}^2.$$

Similar methods could be applied to other complex classifications such as occur when it is desired to split up the general treatment effect into different components, but in practice the analysis of the completed yields will be sufficiently accurate, except in cases where a large proportion of the results are missing. In such cases the direct fitting of constants may prove the easier method of approach.

In the example already given seven degrees of freedom for treatments may be split up in the analysis of the completed set of yields into seven single degrees of freedom, corresponding to direct effects and first and second order interactions, but it is unnecessary to proceed farther with the analysis here, which is better made in conjunction with the other part of the experiment (not reproduced).

6. *Errors of treatment means.*—If the main tests of significance are made by means of an analysis of variance there is no need to make any very precise determination of the standard errors of the treatment means. Nevertheless the provision of standard errors is useful as an indication of the accuracy of the results, and it will therefore be of interest to see what differences are made by missing plots.

When only a single plot is missing the treatment mean containing the estimated value of the missing plot can easily be expressed as a linear function of all the known yields, whence its variance can be calculated in the ordinary manner. If σ^2 is the variance of a single yield, the variance in the case of a randomized block is, in the previous notation,

$$\frac{1}{q} \left\{ 1 + \frac{p}{(p-1)(q-1)} \right\} \sigma^2,$$

and in the case of a Latin square it is

$$\frac{1}{p} \left\{ 1 + \frac{p}{(p-1)(p-2)} \right\} \sigma^2.$$

The variances of the other treatment means are, of course, σ^2/q and σ^2/p respectively. Thus in a randomized block experiment with six treatments and four replications the variance is 1.40 times what it would have been with no plot missing, and in a 5×5 Latin square 1.42 times. The variance of the differences of this and any other mean is therefore in both these cases about 1.2 times what it should have been. In other words the significant difference is about 10 per cent. greater.

When only one plot is missing the treatment mean containing this plot is uncorrelated with the other treatment means, and therefore the variance of the difference of two means is the sum of the variances of these means. If more than one plot is missing this is in general only true of differences between means, one of which contains no missing plot. Consequently, in order to find the variance of the difference of two treatment means both of which contain missing plots, it is necessary to express the difference of the two means as a linear function of the known yields. If the number of missing plots is greater than two or three this involves heavy algebra, which is not worth while. An alternative method of approach by fitting constants directly and inverting the determinant is equally laborious.

Although when a number of plots are missing the computation of the standard errors of the differences of treatment means is not practicable, in the case of a randomized block it is easy to fix upper and lower limits between which the errors must lie. A lower limit is provided by ignoring the block classification altogether, and an upper limit by rejecting all those blocks which do not contain both treatments. Thus in the experiment already considered the variance of the difference between the treatment means for NP and NK must be greater than $(\frac{1}{8} + \frac{1}{8})\sigma^2$ and less than $\frac{3}{8}\sigma^2$, i.e. it must lie between $0.235\sigma^2$ and $0.286\sigma^2$. A good working rule is to give half weight to each plot of a treatment which has no corresponding plot in the same block belonging the other treatment. This will give $(\frac{1}{7.5} + \frac{1}{8})\sigma^2$, or $0.258\sigma^2$ as the value of the variance in question.

A similar rule might be formulated for a Latin square, each yield which has the corresponding yield of the other treatment missing in either row or column being given a weight of $\frac{2}{3}$, or $\frac{1}{3}$ if both the corresponding yields are missing.

7. *Use of the missing plot technique in testing interactions.*—In an ordinary analysis of variance it sometimes happens that when a set of interactions is found to be significant, there is a probability that the whole of this significance may be accounted for by a single outstanding value. This hypothesis may be rigorously tested by omitting the outstanding value, and supplying a new value in its place by means of the formula for a missing plot. The new variance for interaction (the number of degrees of freedom being diminished by one) can then be calculated and tested. The procedure is best illustrated by an example.

Example.—Table 5 gives the logarithms of the mean yields of four varieties of cotton at seven different centres. At each centre a 4×4 Latin square was laid out. Logarithmic yields are taken in order to equalize the variances at different centres, the standard errors being found to be roughly proportional to the mean yields. The estimate of the variance of a single entry of the table from the variances at the different centres was found to be 0.0008686.

TABLE 5

Centres	A	B	C	D	Total	$D - \frac{1}{3}(A+B+C)$
1	0.190	0.097	0.149	0.246	0.682	0.101
2	0.528	0.538	0.450	0.593	2.109	0.088
3	0.200	0.276	0.238	0.356	1.160	0.088
4	1.021	0.959	0.981	1.248	4.209	0.261
5	0.164	0.176	0.149	0.233	0.722	0.070
6	0.566	0.546	0.494	0.627	2.233	0.092
7	0.650	0.614	0.601	0.647	2.512	0.025
Total	3.409	3.206	3.062	3.950	13.627	..

The analysis of variance is given in Table 6. Varieties, places, and the interactions between them are all significant. The last column of Table 5, giving the difference between D and the mean of the other three varieties, indicates that the extra high yield of D at the high yielding centre, 4, is exceptional, and may therefore account for most of the interaction.

TABLE 6

	Degrees of freedom	Sum of squares	Mean square	z
Varieties .	3	0.064897	0.021632	..
Places .	6	2.316032	0.386005	..
Interactions .	18	0.032653	0.001814	0.3680
Total .	27	2.413582	..	..
Error .	42	..	0.0008686	..

The value of the yield of *D* given by the missing plot formula is 1.064. The new analysis of variance based on this value is given in Table 7.

TABLE 7

	Degrees of freedom	Sum of squares	Mean square
Varieties .	3	0.039965	0.013322
Places .	6	2.115157	0.352526
Interactions .	17	0.010941	0.000644
Total .	26	2.166063	

The interaction mean square is now below expectation, and the single abnormal value therefore accounts entirely for the original significance. The sums of squares due to varieties and places are also reduced in the new analysis. This is to be expected since the average varietal and place effects excluding the anomalous value of *D* at 4 are now what are approximately represented. Tests of significance may be made if so desired. The difference between the original and new interaction sums of squares, 0.021712 (one degree of freedom) also gives a valid test of significance which may be employed to test a single outstanding value when interactions as a whole are not significant, if there is a *a priori* ground for believing that this value may in fact be different from the others.

Summary.—The procedure introduced by Miss Allan and Dr. Wishart for supplying a missing value in a table of experimental results, such as the plot yields of a field trial, so that the treatment means form unbiased and efficient estimates of the treatment effects, is here extended to enable any number of missing values to be replaced, it being shown that the method of derivation adopted previously is equivalent to the simpler method of minimizing the error term in the ordinary analysis of variance. The solution of a complex example is effected by iterative methods.

The validity of analysis of variance on the completed table of values is investigated. It is shown that when the degrees of freedom allotted to error are reduced by the number of values replaced, there is little disturbance, provided that the number of missing values is not too great. Such disturbance as there is always exaggerates the significance of the results. The standard errors of the treatment means are also briefly discussed.

The use of the missing-plot technique for further analysing interactions, whose significance is believed to be due to a few anomalous values, is illustrated by the analysis of a set of varietal trials on cotton.

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(Received January 11, 1933)

On the Evidence Against the Chemical Induction of Melanism in Lepidoptera.

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(Received November 30, 1932.)

1. *Introductory.*

McKenny Hughes (1932) has reported an experiment, carried out at Merton, in which the moth *Selenia bilunaria* Esper was fed on leaves treated with lead nitrate and manganous sulphate. In the generations following these treatments no instance of a moth showing the melanic recessive mutation, reported by Harrison and Garrett (1926), was recorded.

In the discussion contributed by Haldane (McKenny Hughes (1932), p. 400) it is argued that the results are significantly in conflict with the findings of Harrison and Garrett in that these authors recorded 6 melanics out of 142 moths of the generations following treatment, while McKenny Hughes found no melanics among 910 moths. This difference, as Haldane claims, would be highly significant, if the several individuals counted had an independent chance of being melanics. In both lots, however, the moths were in reality closely related, and the chances cannot on any theory be considered independent. The other calculations in Haldane's discussion are open to the same criticism.

The value of a negative finding, unlike that of a positive result, such as that reported by Harrison and Garrett, rests exclusively on the extent of the evidence. The different broods reported by McKenny Hughes are not only of different sizes, but of several different kinds, having very different weight as negative evidence. Thus, to take the lead series only, in family C there are 21 broods, comprising 132 moths, all in the first generation following treatment with lead. In family D there are (a) 12 broods comprising 220 moths in the first generation following treatment, (b) two broods of 49 moths after two generations of treatment, and (c) one brood of 25 moths the parents of which had been off lead for one generation. Finally, in family G there are (a) 14 broods comprising 209 moths in the first generation following treatment, (b) 8 broods comprising 138 moths after two generations of treatment, (c) 8 broods comprising 43 moths off lead for one generation, (d) 12 broods comprising 83 moths after three generations of treatment, and (e) 2 broods comprising 7 moths off lead for two generations.

Table I shows the combined totals for the three families.

Table I.—Number of broods and moths bred.

	One generation treatment.	Two generations treatment.	Three generations treatment.	Off lead one generation.	Off lead two generations.	Total.
Broods	47	10	12	9	2	80
Moths	561	187	83	68	7	906

The small discrepancies from Haldane's values are presumably to be ascribed to errors of transcription. It will, however, make no appreciable difference whether the error is in the tables printed with McKenny Hughes' paper, or in the totals given by Haldane.

The value of the material as negative evidence may be measured by the rates of mutation which, in the light of the observations, can be shown to be highly improbable. An infinitude of observations would be required to show that lead treatment had actually zero effect on the mutation rate. Any body of data showing no mutations may be accepted as proving the non-existence of mutation rates above a certain critical level; the more extensive the observations, and the more relevant they are to the point at issue, the smaller will this critical level be made. In particular we may ask, for the body of material presented, for what mutation rate the probability of observing no melanic moths will be reduced to 0.05 or 0.01. The experiment might then be interpreted as proving, with degrees of certainty measured by these two levels of significance, that the mutation rate did in fact not exceed the corresponding value found. These critical mutation rates will be evaluated in the following sections.

2. *Definition of Mutation Rate and Form of Calculation.*

The probability of the absence of visible mutants in a given series of affiliated progenies will be determined not only by the mutation rate, but by the stage at which the mutations are supposed to occur. By hypothesis A we shall denote the view that a mutation rate μ per generation implies that a non-mutant individual will after treatment produce a fraction μ of mutant gametes, and a fraction $(1 - \mu)$ of non-mutant gametes. A heterozygous individual, on the other hand, will produce $\frac{1}{2}(1 + \mu)$ mutant gametes, and $\frac{1}{2}(1 - \mu)$ non-mutant gametes. There will, therefore, on this hypothesis, be only three types of mating to be considered, as shown in Table II.

Table II.—Frequency of the three kinds of offspring from the different types of mating.

Mating.	Offspring.		
	MM.	Mm.	mm.
MM × MM	$(1 - \mu)^2$	$2\mu(1 - \mu)$	μ^2
MM × Mm	$\frac{1}{2}(1 - \mu)^2$	$\frac{1}{2}(1 - \mu)(1 + 2\mu)$	$\frac{1}{2}\mu(1 + \mu)$
Mm × Mm	$\frac{1}{4}(1 - \mu)^2$	$\frac{1}{2}(1 - \mu^2)$	$\frac{1}{4}(1 + \mu)^2$

Thus if μ is 3 per cent., the proportionate frequencies of melanic moths in the three types of mating will be 0.0009, 0.01545, 0.265225, and if the progeny yields s moths, the probabilities that all shall be non-melanic will be $(0.9991)^s$, $(0.98455)^s$ and $(0.734775)^s$. Columns (c), (d) and (e) of Table III give, in reverse order, these probabilities for the sixth generation (the third after treatment), using $\mu = 3$ per cent. for the offspring of treated moths, and $\mu = 0$ for the offspring of the untreated. It will be observed that families over ten have only a small probability of being the offspring of two heterozygotes, but that even the large family of 33 might well have been the offspring of a heterozygote and a homozygote.

The probabilities of the three possible matings producing the sixth generation may be used to calculate the probabilities of these same alternatives in the fifth generation. Thus from a mating of homozygotes the probability that both the offspring chosen for mating shall be homozygotes will be $(1 - \mu)^4$, the probability that one shall be a homozygote and one a heterozygote will be $4\mu(1 - \mu)^3$, and the probability that both shall be heterozygotes will be $4\mu^2(1 - \mu)^2$. If, therefore, the mating, which produced the fifth generation progeny, was one between non-mutant moths, the probability that a pair of its members mated *inter se* will produce s offspring non-mutant in appearance, will be

$$4\mu^2(1 - \mu)^2 \{1 - \frac{1}{4}(1 + \mu)^2\}^s + 4\mu(1 - \mu)^3 \{1 - \frac{1}{2}\mu(1 + \mu)\}^s + (1 - \mu)^4 \{1 - \mu^2\}^s,$$

or, with a 3 per cent. mutation rate, the sum of the values in columns (c), (d) and (e) of Table III, multiplied in order as they stand by 0.003387, 0.109521, 0.885293, respectively. The values in column (h) in Table III have been obtained by using these factors,

Table III.—Calculation of probabilities—first stage.

Sixth generation brood. (a)	Moths. (b)	Fifth generation mating.			Fourth generation mating.			Brood of parents. (i)
		Mm × Mm. (c)	MM × Mm. (d)	MM × MM. (e)	Mm × Mm. (f)	MM × Mm. (g)	MM × MM. (h)	
GL18/30J	1	0.73478	0.98455	0.99910	0.47003	0.89157	0.99481	} GL17/30S
GL17/30J	1	0.73478	0.98455	0.99910	0.47003	0.89157	0.99481	
GL14/30J	7	0.11563	0.89674	0.99371	0.29458	0.68426	0.97833	
GL13/30J	3	0.39670	0.95436	0.99730	0.37847	0.78721	0.98877	GL12/30S
GL16/30J	2	0.53989	0.96934	0.99820	0.41777	0.83250	0.99169	} GL11/30S
GL12/30J	5	0.21418	0.92510	0.99551	0.32594	0.72442	0.98336	
GL15/30J	33	0.00004	0.59820	0.97072	0.19431	0.21484	0.92489	} GL7/30S
GL8/30J	10	0.04587	0.85581	0.99104	0.26741	0.64543	0.97125	
GL11/30J	12	0.02476	0.82957	0.98925	0.25587	0.62676	0.96672	} GL6/30S
GL9/30J	7	0.11563	0.89674	0.99371	0.29458	0.68426	0.97833	
GL5/30J	1	0.73478	0.98455	0.99910	0.47003	0.89157	0.99481	} GL2/30S
GL4/30J	1	0.73478	0.98455	0.99910	0.47003	0.89157	0.99481	
GL10/30J	5	0.23730	1	1	0.37182	0.80932	1	} GL4/30S
GL3/30J	2	0.56250	1	1	0.45312	0.89062	1	

Similarly column (g), representing the supposition that the fifth generation brood was derived from the cross of a homozygous non-mutant with a heterozygote, is obtained by multiplying the same quantities by the factors

$$\frac{1}{4}(1 - \mu)^2(1 + 2\mu)^2, \quad \frac{1}{2}(1 - \mu)^3(1 + 2\mu), \quad \frac{1}{4}(1 - \mu)^4,$$

or numerically by 0.264299, 0.483717, 0.221323 for a 3 per cent. mutation rate, or by 0.25, 0.50, 0.25 for zero mutation rate.

Finally, the factors for the supposition that the fifth generation brood was derived from the mating of two heterozygotes are

$$\frac{1}{4}(1 - \mu^2)^2, \quad \frac{1}{4}(1 - \mu^2)(1 - \mu)^2, \quad \frac{1}{16}(1 - \mu)^4,$$

or, numerically, 0.249550, 0.235013, 0.055331 and 0.25, 0.25, 0.0625 for $\mu = 0.03$, and zero respectively. These factors are used to obtain the values in column (f).

We are now in a position, for any progeny of the fifth generation, to express the probability of each of the three possible types of mating from which it might have been derived, taking into account not only the composition of the fifth generation, but also of that of the broods derived from it. Thus brood

GL17/30S consists of 15 moths of which three pairs have been used in the production of the sixth generation broods GL18/30J, GL17/30J and GL14/30J. Apart from the sixth generation the probability that this fifth generation brood had been derived from a mating of two heterozygotes would have been $(0.734775)^{15}$; taking the sixth generation into account it is now seen to be $(0.734775)^9$, $(0.47003)^2$, $(0.29458)^1$, or 0.00406 as set down in Table IV. The index of the first power is 9 and not 15, since the chance that the 6 moths used as parents should be non-mutants has already been taken into account in the three corresponding factors. Columns (c), (d) and (e) of Table IV, derived thus from columns (f), (g) and (h) of Table III, show that many of the fifth generation progenies were sufficiently large to exclude, as improbable, the idea that they were from the mating of two heterozygous mutants; while for only one of the progenies, GL7/30S, a large brood from which two satisfactory broods had been derived, is there shown a low probability of its having one mutant parent.

Table IV.—Calculation of probabilities—second stage.

Fifth generation brood. (a)	Moths not mated. (b)	Fourth generation mating.			Third generation mating. (h)	Brood of parents. (i)
		(c)	(d)	(e)		
GL17/30S	15-6	0.00406	0.47280	0.96038	0.90200	GL16/29J
GL11/30S	30-4	0.00004	0.40231	0.95262	0.88741	GL15/29J
GL16/30S	4	0.29148	0.93962	0.99640	0.98600	GL14/29J
GL12/30S	19-2	0.00201	0.60414	0.97375	0.92823	} GL11/29J
GL7/30S	29-4	0.00002	0.09395	0.87830	0.78784	
GL6/30S	18-4	0.00101	0.34487	0.93391	0.86456	
GL5/30S	1	0.73478	0.98455	0.99910	0.99481	GL6/29J
GL2/30S	22-4	0.00086	0.60061	0.97373	0.92782	GL3/29J
DL7/30S	14	0.01337	0.80414	0.98746	0.96231	DL11/29J
DL5/30S	35	0.00002	0.64665	0.96894	0.92862	DL17/29J
GL15/30S	9	0.07508	1	1	0.99507	} GL7/29J
GL10/30S	6	0.17798	1	1	0.99542	
GL9/30S	2	0.56250	1	1	0.99672	
GL8/30S	1	0.75000	1	1	0.99735	
GL14/30S	12	0.03168	1	1	0.99492	} GL10/29J
GL13/30S	6	0.17798	1	1	0.99542	
GL4/30S	6-4	0.09477	0.72081	1	0.96456	} GL4/29J
GL3/30S	1	0.75000	1	1	0.99735	
DL1/30S	25	0.00075	1	1	0.99482	DL7/29J

For an experiment extending over many generations the cycle of operations set out above may be repeated indefinitely. Since in the experiment under discussion, the third generation was the first to be treated, the only hypothesis to be considered as to the origin of the fourth generation is that its parents were in each case both homozygous non-mutants. Consequently, columns (*f*) and (*g*) will not be needed in Table IV, and only column (*h*) will have to be calculated; the formula for treated moths is at this stage used in every case. The 19 pairs of the fourth generation, which had progeny, have accounted for 38 moths, leaving 523 others each with a probability 0.9991 of being a mutant. The product of the 19 values shown in column (*h*) of Table IV, multiplied by 0.9991 to the power of 523, will therefore give the probability of the observed negative result, on the hypothesis of a 3 per cent. mutation rate specified by hypothesis A.

The product of the 19 values comes to 0.43209, and the power of 0.9991 to 0.62446. The final probability of the whole series of observations is therefore 0.26982; hence the experiment is far from excluding the possibility of a mutation rate of 3 per cent.

On repeating the calculations with a 10 per cent. mutation rate, the product of the contributions of the 19 families of the fifth generation is 0.0013216, while 0.99 to the power of 523 contributes a factor 0.0052145. The probability of such a negative result as that observed, if there had been a mutation rate, as defined, of 10 per cent., is only 6.8915 millionths. The observations thus effectively exclude this possibility.

The logarithm of the probability evidently increases, in the range considered, more rapidly than the first power, though not quite so rapidly as the second power of the mutation rate. Interpolating logarithmically, the 1 per cent. point is found to be at a mutation rate of about 6.0 per cent., and the 5 per cent. point at about 4.7 per cent.

Since the logarithm of the probability increases proportionately with the bulk of the data, supposing these to be of the same kind, it may also be inferred that to exclude mutation rates exceeding 1 per cent. per generation would have required about 17 times as many observations as those reported if we were satisfied with the 5 per cent. level of probability, or about 26 times as many to reduce the probability to 1 per cent.

3. *Alternative View of the Action of the Mutations.*

The data of Harrison and Garrett are not in accordance with the possibility that some 5 per cent. of the gametes of moths treated as larvæ carry the mutant

gene, for then only about 1 in 400 of each brood of the second generation could show the mutation. On the contrary, Harrison and Garrett reported no broods without melanics, and two broods showing 3 melanics and 55 normals. Data of this kind suggest that the mutation, if not already present in the stock, occurred at an earlier stage than has been supposed, so that when a mutation is induced a large proportion of the gametes are affected. We may therefore consider the alternative supposition (B), or, rather, the other extreme of the range of possibilities; namely, that a single mutation affects the whole germ tract, so that a treated non-mutant has a probability $(1 - \mu)^2$ of propagating as a non-mutant, a probability $2\mu(1 - \mu)$ of propagating as a heterozygote, and a probability μ^2 of propagating as a homozygous mutant. This extreme supposition is not that best suited to Harrison and Garrett's data, for it would require those broods in the second generation which contain melanics to show 25 per cent. melanics; actually they show only about 5 per cent., which would be near to expectation if a single mutation affected about half the germ tract of the animal in which the mutation took place. We shall not, however, consider this special possibility, since its characteristics will doubtless be brought out by the more extreme and definite hypothesis to be considered.

The practical computation is, in the case of hypothesis B, a little more complicated than in hypothesis A since there are 5 instead of 3 types of mating to be considered. The two additional types arise when individuals normal in appearance are transformed as progenitors into homozygous mutants. Two types of mating give a proportion of mutant offspring; namely, $Mm \times Mm$ giving 25 per cent. melanics, and $Mm \times mm$ giving 50 per cent. The probabilities of a mating yielding s normal individuals being of these kinds are therefore given by the values $(\frac{3}{4})^s$ and $(\frac{1}{2})^s$ respectively.

A normal individual from either the mating $MM \times mm$ or $Mm \times mm$ is bound to be heterozygous before mutation, and after treatment will be germinally heterozygous in $(1 - \mu)$ cases, and homozygous in μ cases. A pair of such individuals mated will therefore give a mating of type $Mm \times Mm$ in $(1 - \mu)^2$, of type $Mm \times mm$ in $2\mu(1 - \mu)$ and of type $mm \times mm$ in μ^2 cases. Hence the contribution of any progeny of s to the probability that the parent progeny was of either the types $MM \times mm$ or $Mm \times mm$ will be

$$\mu^2 (0)^s + 2\mu(1 - \mu) (\frac{1}{2})^s + (1 - \mu)^2 (\frac{3}{4})^s,$$

which we may write in a more general notation as

$$2\mu(1 - \mu) p_{011} + (1 - \mu)^2 p_{121},$$

where p stands for the probability, as judged by its observed composition, and that of its descendants, that a progeny is of the theoretical composition indicated by the suffix.

Similarly if the parent progeny is of type $Mm \times Mm$, the probability that a normal offspring will propagate as a homozygous normal is $\frac{1}{3}(1 - \mu)^2$, as a heterozygote $\frac{2}{3}(1 - \mu^2)$, and as a homozygous mutant $\frac{1}{3}\mu(2 + \mu)$. The contribution of the offspring of a pair of such normal offspring to the probability that the parental mating is of this type will therefore be

$$\frac{4}{3}\mu(2 + \mu)(1 - \mu^2)p_{011} + \frac{4}{3}(1 - \mu^2)^2p_{121} + \frac{2}{3}\mu(2 + \mu)(1 - \mu)^2p_{010} \\ + \frac{4}{3}(1 - \mu^2)(1 - \mu)^2p_{110} + \frac{1}{3}(1 - \mu)^4p_{100}.$$

In like manner the contribution to the probability that the parental mating is of type $MM \times Mm$ is

$$\frac{1}{2}\mu(1 + 2\mu)(1 - \mu^2)p_{011} + \frac{1}{4}(1 - \mu)^2(1 + 2\mu)^2p_{121} + \frac{1}{2}\mu(1 - \mu)(1 - \mu^2)p_{010} \\ + \frac{1}{2}(1 + 2\mu)(1 - \mu)^3p_{110} + \frac{1}{4}(1 - \mu)^4p_{100},$$

and the contribution to the probability that it is $MM \times MM$ is

$$4\mu^3(1 - \mu)p_{011} + 4\mu^2(1 - \mu)^2p_{121} + 2\mu^2(1 - \mu)^3p_{010} \\ + 4\mu(1 - \mu)^3p_{110} + (1 - \mu)^4p_{100};$$

so that starting from the terminal progenies we may calculate, as before, the probability of the series of non-melanic progeny observed for any chosen mutation rate.

Using a mutation rate of 10 per cent. the probability of the series of normal families observed by McKenny Hughes is found to be 0.0097551, so that 10 per cent. per generation is just over the 1 per cent. value for hypothesis B. One obvious reason for the lower sensitivity of the experiment to hypothesis B, compared with hypothesis A, is that in the first generation following treatment the chance of showing no mutant for a brood of 1 is 0.99 on both hypotheses. On hypothesis A, however, any further members of the brood have an equal and independent chance, so that the probability of s non-mutants is $(0.99)^s$; while on hypothesis B the probability of a non-mutant brood, however large, cannot fall below 0.9639, for this is the probability that one or other of the parents is a non-mutant. The 21 broods of Series C, for example, comprise 132 normal moths, but the probability on hypothesis B of this series of observations is 0.57372, equal to that of about 55 individual moths on hypothesis A, or to 55 broods of one on hypothesis B. Many other examples show emphatically how nearly impossible it is by judgment alone, and without explicit calculations, to gauge the value of negative evidence of this kind.

4. Discussion.

The observations reported by McKenny Hughes are sufficiently extensive to exclude as improbable mutation rates exceeding 6.0 per cent. per generation induced by lead treatment, on the hypothesis that mutations are induced independently in the gametes; for the series of normal families observed would have a probability of occurrence of less than 1 per cent. if the mutation rate had exceeded this value. Less decisively, that is, with a 5 per cent. level of significance, are mutation rates exceeding 4.7 per cent. excluded.

Using the same sort of observations, the amplitude of the material would have to be increased 17-fold in order to exclude mutation rates over 1 per cent. on the lower standard, and about 26-fold to exclude them on the higher standard of significance.

On the alternative view that the mutations affect not individual gametes independently, but the whole germ tract of the individual affected, the observations are still less conclusive, for the probability of the series of normal families observed is only just under 1 per cent. with a mutation rate as high as 10 per cent.

Harrison and Garrett, after a single generation of treatment, mated four moths, all of which acted as partial heterozygotes. Apart from exceptional good fortune, this suggests an enormous mutation rate; for, with a mutation rate of 8 per cent., only about 30 per cent. of the treated moths should act as semi-heterozygotes. With *Tephrosia bistortata*, on the other hand, only a single brood after four generations of treatment yielded a melanic, a result suggestive of a much lower, though still absolutely large, mutation rate.

It is not the writer's purpose to attempt to justify the very remarkable claim put forward by Harrison and Garrett, and it appears by no means impossible that the mutants observed were in reality segregates from a mutation pre-existing in the stock. If it is true that the melanics are less viable than normal moths, the paucity (5 per cent. against 25 per cent. expected) of melanics in the broods in which they first appeared would be explained. The system of experimentation adopted at Merton is, however, quite insufficient to show that chemical agencies do not induce mutations with even more than the high mutation rate of 1 per cent.

To view the matter in perspective we may note that of known physical agencies, the most effective in inducing mutations, namely, irradiation with X-rays, seldom causes a rate of more than one in several thousands at a particular locus. Thus Timoféeff-Ressovsky (1930), whose work I cite as pre-eminent in its thoroughness and extent, reports 15 back mutations in *Drosophila*

melanogaster, out of 213,567 irradiated chromosomes, or a little less on the average than 1 in 14,000. Even to establish the absence of mutation rates exceeding 1 per cent., though sufficient to require a reinterpretation of Harrison and Garrett's observations, would only show that the chemical agency (lead) is not more than 140 times as effective as X-rays are ordinarily found to be.

Had it been possible to test for mutations not by inbreeding only, but by back-crosses to the melanic form, little difficulty should have been encountered, with material not considerably greater than that used by McKenny Hughes, in excluding mutation rates over 1 per cent. For, without inbreeding, but using crosses between different treated families, and in the absence of disease, there can be little doubt that satisfactorily large broods, at least exceeding 10 moths, would have been readily obtained after three generations of treatment. A hundred such broods formed by crossing treated moths with melanics would test 200 chromosomes. With a mutation rate of 1 per cent. for three generations, about 3 per cent. of these should contain mutant genes, on either view of the incidence of mutation, and the absence of all melanics, when six affected families were expected, would be good evidence against a mutation rate of 1 per cent.

The method of attempting to reveal possible mutations by inbreeding, not only introduces difficulties by impairing the stock, but is exceedingly inefficient compared to back-crossing. Since all scientific experiments are limited by the amount of money and labour which can be expended upon them, it is highly desirable that any experiment should be designed so as to use the available resources to the best advantage.

Summary.

A method is given of assessing by calculation the value of evidence of the non-occurrence of recessive mutations under experimental conditions. It appears that the evidence, against the induction of melanic mutations in moths by feeding with lead, is insufficient to disprove the existence of mutation rates up to 5 per cent. or 8 per cent. according to the stage at which mutation is postulated.

Mutation rates of this magnitude would be far greater than those which can be certainly induced by any other agency.

The use of back-crosses instead of inbreeding would increase the value of experimental data of this kind by approximately thirty-fold.

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Selection in the Production of the Ever-sporting Stocks.

BY

R. A. FISHER, F.R.S.

With one Diagram in the Text.

I. *Winge's Theory of Doubleness.*

THE problem of doubleness in stocks, which had been the subject of genetic work at Cambridge from almost the beginning of the century, has been recently cleared up by Winge (O. Winge, 1931, 'The inheritance of double flowers and other characters in *Matthiola*'. *Zeitschrift für Züchtung, Reihe a Pflanzenzüchtung*, xvii. 118-35), by means of extensive experiments of his own, which he finds confirmed by certain unexplained exceptional plants reported by Miss E. R. Saunders as early as 1911.

On Winge's theory the double is a recessive mutant which, since the double flowers are sterile, both as pollen and ovule parent, acts as a lethal. In the ever-sporting races it is balanced by a closely linked pollen lethal. The ever-sporting singles, from which the doubles are derived generation after generation, are thus heterozygous for two closely linked lethals carried in opposite chromosomes. Apart from rare recombinations, the pollen all contains the gene for doubleness, while the ovules are of two kinds, one containing the gene for doubleness, and the other the pollen lethal. Consequently there are produced in each generation nearly half doubles, free from the pollen lethal, and nearly half singles carrying this lethal like their parents. The pollen lethal acts, not only on the gamete, but has also a debilitating effect on the heterozygote; the singles of ever-sporting lines are for this reason relatively weakly plants, compared with the doubles of the same lines, and with singles obtained by out-crossing. Their frequency also shows regularly some slight deficiency compared with the doubles in the same families. This inequality in the numbers surviving to be classified led, for many years, to an elaboration of hypotheses aimed at explaining, by the interaction of two or more factors, the aberrant and irregular ratios observed.

In addition to the offspring produced, as explained above, by

non-crossover gametes, there should, on Winge's hypothesis, be formed a small proportion of normal pollen, which, with the two common types of ovule, will produce two types of single plant bearing either the pollen lethal, or the recessive gene for doubleness, but not both. The second type will also be produced from cross-over ovules. From the progeny of such plants both of these recessive factors will be steadily and automatically eliminated. The pollen lethal could of course only survive in the female line, and even here will be at a disadvantage owing to its debilitating effect. The doubling factor can survive both in pollen and ovules, but since the double plants themselves must be without progeny, the power of throwing doubles could only be retained in the strain by planting different progenies separately, and, in each generation, taking seed only from those singles which had appeared in the same families as doubles. Since this precaution is not needed in the ever-sporting strains of stock, it would certainly not have been taken; and the progeny descended from such cross-over plants, throwing, as long as it was retained, an increasing proportion of singles, would be certainly rejected sooner or later as contaminated seed.

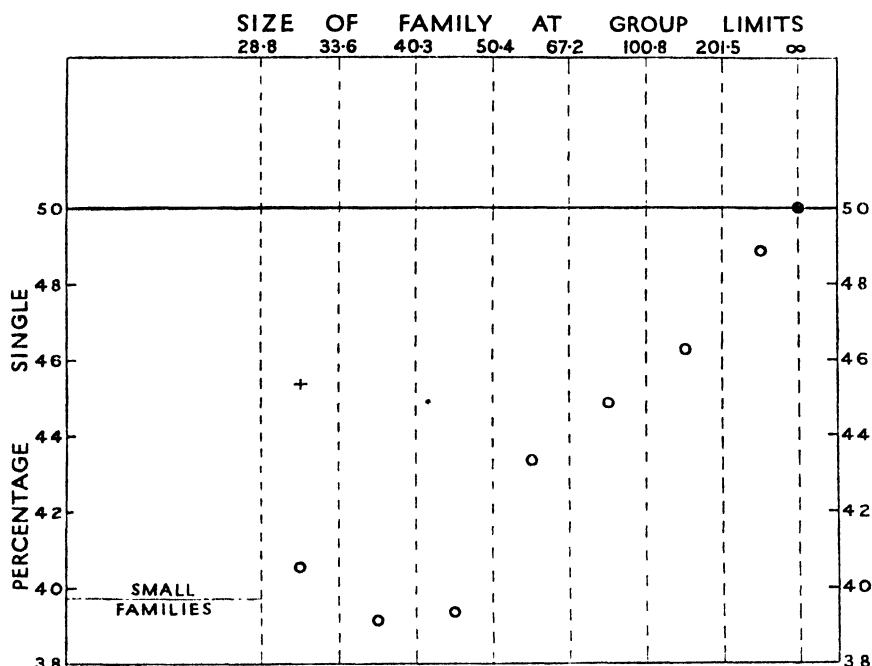
One cross-over plant, from which the pollen lethal had been eliminated, was fortunately used as a parent by Winge, who raised 186 plants from it by self-fertilization; of these 139 were single, and 47 double. Evidently, it differed sharply from the sister plants which gave, as usual, a slight excess of doubles. It was also evidently much more fertile than they were. Only a quarter of the offspring are doubles, and we should therefore expect a second quarter to be pure-breeding singles. Actually, two of the single offspring bred from gave respectively progenies of 945 and 314 plants, all single, while others gave large progenies very closely in the ratio 3:1.

In addition to this well-established case of his own, Winge points out that a probably similar family was reported by E. R. Saunders (1911), ('Further experiments on the inheritance of "doubleness" and other characters in stocks', *Journal of Genetics*, i. 303-76). Of the 87 self-bred families of the Glabrous-red race (Table III, p. 372), the 86th has 23 singles and 8 doubles, numbers strongly suggestive of a 3:1 ratio, and very aberrant from the excess of doubles usually found, especially in the smaller families. Unfortunately, this particular family was not further propagated, so that direct proof of its nature was not obtained. Indeed, it would seem that the unusual ratio which it shows must have been entirely overlooked, since the summary of the results with this strain (p. 307) commences with the words 'Thus every attempt to breed out the doubles proved unsuccessful', a conclusion which must be regarded as most unfortunate in view of the probability that doubleness would have been promptly 'bred out' had the first family which showed a decided deficiency of doubles been used for the purpose. That Winge is undoubtedly right in

regarding the usual excess of doubles as wholly due to differential viability, and this particular family as exceptional will be made clear in the following section.

II. *A Graphical Method of Examining Frequency Ratios.*

The fact, which for many years misled geneticists with regard to the problem of double stocks, was that in the ever-sporting strains, the



○ Circles show tendency of percentage to approach 50 per cent. as families are made larger, i.e. as conditions affecting viability are improved. + shows aberrant value obtained by including the exceptional family.

Diagram showing proportion of singles according to the size of family.

numbers of single and double plants surviving to be classified, were not equal. A significant and fairly regular excess of double plants was constantly observed. Such departure from simple ratios may be due to unequal viability, or equally it may be suspected that a more complex genetic hypothesis is required. A simple graphical device, which, with appropriate data, will readily indicate, on internal evidence, that the whole of the discrepancy must be ascribed to unequal viability, may therefore be of use in other cases. Using the group of 87 Glabrous-red families, which were published by Miss E. R. Saunders in 1911, it will be seen that had any such device been applied to examine the data at this date, no

reasonable doubt would have remained that the ratio of singles to doubles was genetically a 1 : 1 ratio, in spite of the persistent and significant excess of doubles observed in most families.

The method consists in plotting the percentage of singles in families of different sizes. The boundaries between the successive size-classes are chosen to be in harmonic progression, with the upper boundary of the highest class at infinity. The successive boundaries are thus found by dividing some chosen number by 0, 2, 4, 6, . . . Since it is desirable, to avoid ambiguities, that these boundaries shall not be whole numbers, it is as well to choose, as the fundamental number, upon which the sequence is to be based, one that is odd. We require in addition that it shall not be so much as twice as great as the largest family, which in this case has 249 members. Further, since we shall use the same diagram to exhibit the aberrant character of a particular family of 31 members, we can make sure that this family shall be centrally placed in the group in which it falls by choosing a multiple of 31. We shall choose 31×13 , or 403, and use the group limits found by dividing 403 by 2, 4, 6, 8, 10, 12, and 14; the values of which to one decimal place are given at the top of the diagram. All families of more than 28 members can be placed in one of these seven classes; the total numbers of singles and doubles obtained from each class can be enumerated, and the percentage of single plants plotted, as in the diagram. The horizontal line on the left of the diagram indicates the percentage of singles in families of less than 29 individuals, which have not been further subdivided. The Table below shows the totals in the different classes :

Summary of 87 Glabrous-red Families ; Data Plotted in Diagram.

Size of family.	Single.	Double.	Total.	Percentage Single.
Over 201	239	250	489	48.88
101 to 201	433	503	936	46.26
68 to 100	261	321	582	44.85
51 to 67	180	235	415	43.37
41 to 50	102	157	259	39.38
34 to 40	130	202	332	39.16
29 to 33 (all families)	(98)	(118)	(216)	(45.37)
29 to 33 (Omitting 1 family)	75	110	185	40.54
Less than 29	200	303	503	39.76

It will be seen that the first four classes, where the percentages are based on the counts of more than 400 plants, point unmistakably to 50 per cent. (the black spot on the diagram) as the limiting value to which the percentage tends as the causes of mortality are more and more thoroughly removed. It has happened in this material that size of family has provided a sufficiently good basis for estimating the favourableness of the conditions in which the plants were reared, and, by extrapolation, for

inferring the genetic ratio appropriate to ideal conditions. In other cases it might be necessary to use germination percentage rather than size of family as a basis for classification. The method merely brings to our notice such indications, whether they are only slight, or, as in this case, so strong as to be decisive, as the data happen to contain. That the internal evidence should be so decisive, is a remarkable tribute to the intrinsic excellence of the data.

We may now consider the exceptional family with 23 single against 8 double plants. A glance at the diagram shows that the expectation for families of this size is about 40 per cent. singles, or roughly, 12 single plants to 19 double. The existence of families with a large excess of doubles (e.g. 9 singles to 23 doubles in family 6) would therefore be not intrinsically improbable, and their occurrence would be no reason for disregarding the family with an exceptional excess of singles. If any doubt remained on this point, or if this particular family had been overlooked, the percentage of singles obtained for this size-class, and represented by a cross on the diagram, would have shown that the inclusion of this family had been sufficient to disturb the average of its class, to an extent which the regularity of the other points shows at once to be inadmissible.

The same diagrammatic examination of the frequency ratio, would therefore, in this case, have provided decisive evidence that the discrepancy from a 1 : 1 ratio was due to differences of viability only ; and, at the same time have drawn attention to the really exceptional character of family 86.

III. *Modification of Linkage Intensity.*

In discussing the origin of the ever-sporting type Winge (p. 131) naturally suggests that the first step was the occurrence of the mutation for double flower, which can at first only have been perpetuated by the continual selection by the growers. Selecting singles from families, or seed batches, which threw the highest proportion of doubles they would have immediately seized upon and brought into general prevalence the ever-sporting type of single, as soon as the pollen lethal had occurred in the single-bearing chromosome of a heterozygote. Winge quotes Miss Saunder's conclusion that the ever-sporting combination must have come into existence before the end of the seventeenth century, possibly not long after the double-flowered type was first known, but he does not call attention to the interesting process of selection which, according to his theory, must have taken place during the 200 or 250 years, since the pollen lethal was introduced. During this period the ever-sporting types of stock must have retained, generation after generation, only the progeny of non-cross-over gametes, for the cross-overs, as we have seen, would rapidly degenerate into singleness, and, though they might occasionally form new single

varieties, the effect is the same as though they were necessarily discarded, for their germ plasm will not again be introduced into the ever-sporting strain. Within such strains, therefore, selection must constantly have favoured closer linkage, and this explains what would otherwise have to be regarded as a somewhat remarkable coincidence, namely, that the lethal needed to balance the doubleness should have occurred exactly where the gardener wanted it, or at least within about 1 cross-over unit of the gene for doubleness. Recognizing that cross-overs have been rigorously eliminated we might suppose, on the other hand, that the cross-over percentage originally was as high as 10, perhaps, or 20 per cent. and that it has been lowered progressively by the selective elimination of those strains in which recombination took place most freely.

The conclusion that the extremely close linkage observed is due to the recent action of relatively intense selection is supported by three further facts :

(i) Although two of the races used by Miss Saunders, the Glabrous-red and the Sulphur-white, were composed entirely of ever-sporting individuals, yet the Glabrous-white and Cream plants were mixed in type, some breeding true to singleness, others throwing three singles to one double, and others again throwing an excess of doubles like other ever-sporting plants. On Winge's hypothesis such a mixture would inevitably arise sooner or later in the propagation of pure lines of seed, without any outside contamination, simply by the occasional occurrence of cross-overs, and the elimination of doubleness in their descendants. The frequency of such impure batches of seed, suggests that in most strains the frequency of recombination is higher than in the reliable ever-sporting strain tested by Winge.

(ii) An even more striking example of the continued existence of occasional individuals with relatively high frequencies of recombination is afforded by plant K of Miss Saunders's Cream line. Progenies were grown from 49 single-flowered offspring of this plant and of these, though certainly the majority were true to the ever-sporting type, at least five showed good 3:1 segregations, and five more gave only singles. Winge says 'Miss Saunders is herself at a loss for an explanation of the phenomenon, and my theory does not give any satisfactory explanation either. For it would imply a rather frequent crossing-over, and this is contrary to the findings in other experiments. I am rather inclined to think that we are here dealing with an experimental error, but, of course, it is not very satisfactory to try to explain the results of other investigators by ascribing them to some slip in the technique'.

Now if the close linkage observed in some reliable ever-sporting strains is due to the selection of the last 200 years it is by no means improbable that other less reliable strains have persisted in which the

frequency of crossing-over is considerably higher. In such strains we should expect most frequently to come across such an apparent 'mixture of seed' as is noticed by Miss Saunders, and also such plants as K of the Cream strain, which, while still of the balanced-lethal constitution, have so high a rate of crossing-over, that, if they are largely used as parents, their offspring will rapidly show signs of such mixture. There is thus no reason to suspect a slip in technique and, indeed, the plant may be cited as a remarkable confirmation of one of the most interesting consequences of Winge's theory.

(iii) The effect of selection in favour of close linkage between two loci must be to diminish principally the crossing-over between them; but also, presumably in less degree, in the two adjacent segments of the same chromosome. Its observational effect will therefore be to shorten greatly in the intervening segment, and to some extent elsewhere, the map length of the chromosome in question, and so to increase the probability of other close linkages found in the same chromosome. It is therefore relevant to the view that the close linkage between the factor for doubleness and the pollen lethal found with it, in ever-sporting strains, has been produced by the selection inherent in the propagation of these strains, that these two factors are both closely linked with the factor for yellow plastids.

SUMMARY.

1. An outline of Winge's theory of doubleness in stocks is given, and of its implications.

2. A simple method of diagrammatic representation applied to Miss Saunders's data of 1911, shows both that the observed excess of doubles is due solely to their greater viability, and that one family there reported was exceptional in giving only one quarter doubles, as should the progeny of a plant freed from the pollen lethal.

3. The close linkage between the pollen lethal and the factor for doubleness is due to selection acting automatically in the propagation of the ever-sporting lines, which has thus built up the ever-sporting character.

EXPERIMENTAL METHODS FOR THE STUDY OF SOIL CULTIVATION

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WITH PLATE 9

Introduction

IN all countries that now have a developed agricultural system, the various cultivation operations, and the implements needed, were empirically evolved at a relatively early date. Hence the efficiency of the operations has, with good reason, been implicitly accepted by agriculturists, and in the host of agricultural experiments of all kinds now on record, little or no reference is made either to the preparation of the land, or the possible effect on the results of the kind of tilth actually obtained. It is not suggested that this is a vital, or even an important, omission in many experiments, since—to take the common case of manurial trials for example—they are designed to ascertain the comparative yields from different manurial treatments, and it is tacitly assumed that the influence of cultivation operations will only affect the general level of yield from the whole experiment. Nevertheless, obscure interactions between the cultivation operations and the various manurial combinations under trial may occur, and thus produce a differential effect on the yields.

So far as experiments on cultivation are concerned, the majority refer to the effect on yield of simple changes in the depth, frequency, and time of incidence of standard operations such as ploughing and harrowing.

The direct study of cultivation processes has only recently been taken up in any detail. Apart from the obvious factor of weed-destruction, we may regard cultivation as a mechanical aid to the formation of the small soil aggregates—or crumbs, or ‘compound-particles’—that are characteristic of a soil in good tilth. The primary effect is a disintegration of large pieces of soil into smaller ones. The experiments¹ on which the present paper is based, deal with this aspect of the problem, in relation to different implements and weather conditions. The conclusions refer only to the Rothamsted soil—a medium to heavy clay loam containing numerous flints—under a temperate climate with a well-distributed rainfall. As it is desirable that experiments should also be done under different conditions of soil and climate, certain important details of experimental procedure are included in this paper for guidance.

Methods of Experiment

The design of a cultivation experiment in conformity with statistical requirements presents certain minor difficulties. A compact group of plots, either as a Latin Square or a randomized block is not always feasible; a headland is needed at each end of a plot for turning the implement and, when ploughing is under investigation, there are,

¹ Keen et al.: *J. Agric. Sci.*, 1930, 20, 364–89.

occasionally, difficulties connected with the casting and gathering of the furrows across the 'lands'. The latter problem can usually be met by arranging the width of each plot to be just under one-half of a 'land', so that the half-ridge and the half-furrow of each half-land fall in the narrow strips bordering the actual plots, which are later used as dividing paths; thus, any irregularities of crop-growth due to the ridge and the furrow are excluded automatically from the experiment. It is desirable to reduce

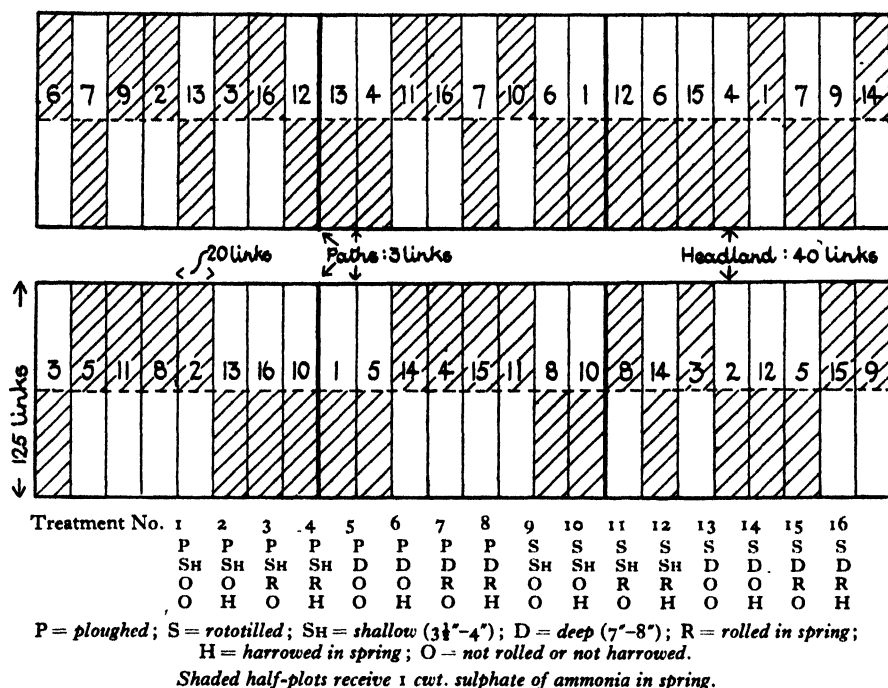


FIG. 1. Design of a cultivation experiment.

to a minimum the gradual slope of the soil from the open furrow to the ridge. A one-way plough can sometimes be used with advantage.

The most satisfactory arrangement is to employ long narrow plots side by side, with a headland at each narrow end. Alternatively, two or more rows of such plots can be used, with common headlands between the rows. Fig. 1 shows the design, drawn up by the Statistical Department, for a cultivation experiment on wheat laid out at Rothamsted in the present season. There are 48 plots in two rows of 24, and each plot is 125 links \times 20 links (1 link = 0.66 ft.). The four winter treatments under test were deep and shallow ploughing, deep and shallow rototillage; on these, certain spring cultivations and manuring are superimposed. By confounding with block differences certain of the less important high-order interactions, the experiment was reduced to six randomized blocks of eight plots each, with a total area of about 1.3 acres.

It is desirable—especially in an uncertain climate—that the size and complexity of the experiment should be such that it can be executed in one day with the labour and supervision available, since if rain falls before the cultivations are completed, the character of the tilth on the plots cultivated after the rain may differ from that on the others. Further, the experiment should be begun whenever possible in reasonably settled weather, to meet the chance of unavoidable delays in completing the cultivations. Thus, in the Rothamsted experiment, already mentioned, the 24 plots scheduled for horse-ploughing were comfortably finished by one team in the day; the rototilled plots required a portion of the following morning for completion, partly owing to delays caused by tine breakages, but mainly because of underestimation of the time needed for the 12 plots subjected to deep rotary cultivation.

The possibilities of errors and delays are much lessened if all preliminary operations connected with the siting and marking of the plots are carried out beforehand, and if one assistant is allotted the sole task of supervising the cultivation teams and their drivers to ensure that all plots receive their correct cultivation treatments.

The main experimental measurement made on the cultivation plots is the degree of mechanical comminution of the soil produced by the implement. Samples of soil are taken immediately before and after the cultivation, and each sample is passed through a nest of graduated sieves, and the weight of soil remaining on each sieve is measured on a spring balance. Samples are taken with a flat-bladed spade. The equipment is shown in Fig. 2 (Plate 9). Three of the sieves have square apertures of 1.5, 0.5, and 0.25 in. side; the fourth is more conveniently made from the usual 3 mm. round-hole perforated brass sheet, and can be taken as approximately equivalent to 0.1 in. square mesh; the remaining unit collects all soil passing the fourth sieve.¹

In taking a pre-cultivation sample, a block of soil is isolated by making four vertical cuts with the spade and it is then removed by an approximately horizontal cut at the depth to which cultivation will be given on that particular plot. The aim is to isolate the block with the minimum of either compression or rupture. The block is gently transferred from the spade to the topmost sieve, and the whole nest is rotated to and fro about its axis for a short while. It will be found that the sieving of a sample is completed quickly; the greater bulk of the soil passes through to its final position in the first few rotations of the sieves. The soil on each sieve and in the pan under the smallest mesh sieve is then transferred to sheets of stout paper and weighed separately, giving five groups: (a) lumps greater than 1.5 in. square; (b) between 1.5 and 0.5 in.; (c) between 0.5 and 0.25 in.; between 0.25 and 0.1 in.; and less than 0.1 in.

The post-cultivation samples are similarly dealt with, except that the four vertical cuts can usually be omitted.

In any sample some of the lumps are only weakly coherent, and would quickly split along lines of weakness into smaller fragments, even if left undisturbed. The gentle action of sieving resolves such lumps into their

¹ Sets of sieves to these specifications are obtainable from A. Gallenkamp & Co., Ltd., 19-21 Sun Street, Finsbury Square, London, E.C. 2.

constituent parts. Thus, although the sieving data give a higher degree of fragmentation than exists in the soil sample before sieving is done, the value is more representative of the actual condition of the soil.

Care must be exercised when taking the post-cultivation samples not to trample unduly the freshly cultivated soil. If most of the samples are taken before the cultivation of the plot is completed, it is not necessary to stand on the cultivated soil at all, either to take the sample or to sieve it. If the cultivation of a plot is completed before all the post-cultivation samples have been drawn, the paths between the plots should be used for access to a point near which the sample is to be taken.

It is necessary to take a number of samples to obtain a reliable average result, as, owing to soil heterogeneity,¹ considerable variation is found in the values for individual samples. In an experiment with the number and size of plots shown in Fig. 1, not less than two pre-cultivation and two post-cultivation samples per plot is desirable.

In the Rothamsted experiments an appreciable proportion of large flints is occasionally left on the upper two sieves. On the whole it is better that these should be discarded before weighing the sieve contents.

The weighings are not corrected for the soil-moisture present, as this does not affect the comparisons between the pre-cultivation and post-cultivation results. Separate samples are taken for determination of moisture-content, primarily for the purpose of facilitating comparisons of sieving results in different seasons. They also serve to show whether there is any appreciable variation in moisture-content over the area under experiment; normally, only insignificant variation is found.

It is important that the sieving tests, like the cultivations, should be finished in a day. The experiment illustrated in Fig. 1 was well within the capacity of three teams of workers. A specific allocation of duties between the members of a team is essential for avoiding errors in sampling and recording. A team should consist of three workers: one to take the samples, a second to sieve and weigh them, and a third to record the weights and the reference letters for plot and sample.

In order to avoid delay to the cultivating teams, samples may sometimes have to be accumulated faster than they can be sieved and weighed. In such a contingency, the third member of the sieving team is able to give assistance in sampling, and also to ensure the correct identification of the accumulated samples. In general, it has been found that two teams of three workers can deal with the same number of samples as three teams of two workers, and with less chance of mistakes.

Fig. 3, which illustrates the kind of information given by sieving records, has been constructed from data obtained under very different conditions. The values for 1926 were obtained during an experiment on spring cultivation, following a hard frosty winter; those for 1928 refer to a similar experiment following a wet open winter. The experiments were not done on the same field, but in mechanical composition and physical behaviour the soil in the two fields is practically identical. Comparison of the pre-cultivation results for 1926 and 1928 clearly

¹ See Keen and Haines, *J. Agric. Sci.*, 1925, 15, 375-406; and Keen and Cashen, *J. Agric. Sci.*, 1932, 22, 126-34, for experimental evidence on this point.

shows the predominant influence of weather conditions on tilth. In 1928 the drastic action of a combined rotary cultivation and ridging was needed to produce about the same final disintegration as was achieved in 1926 merely by the gentle action of sieving the pre-cultivation samples. The 1926 results show that the soil was already in excellent condition before the cultivations and hence almost any form of stirring would have been capable of producing a satisfactory tilth. In 1928, on the other hand, the soil contained a predominance of large coherent lumps. It will be observed that the ridging or bouting plough is a very effective implement for producing soil disintegration—more so than rotary cultivation in this

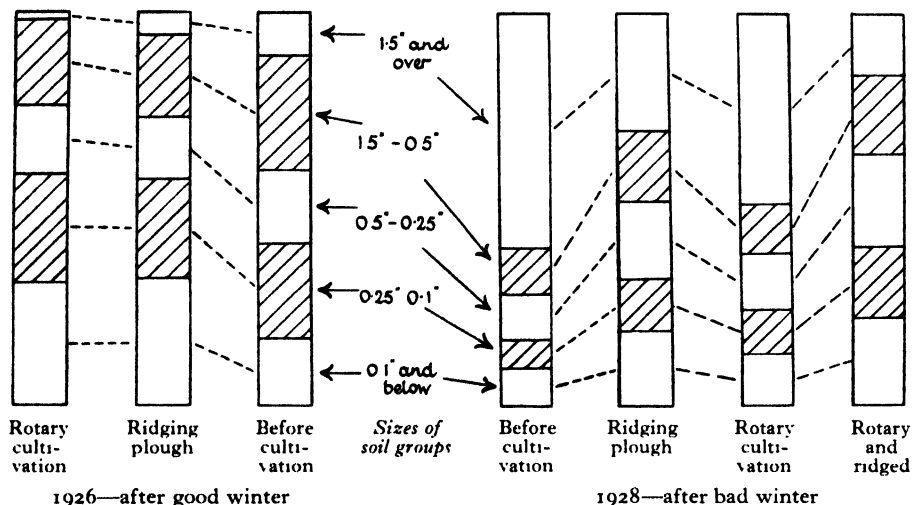


FIG. 3. Percentage disintegration by sieving tests, showing effect of weather and cultivation on soil.

experiment. This action of the ridging plough has also been observed in other experiments; it is in contrast with the ordinary plough which, unless it is of the concave or 'digger' mouldboard type, is used primarily as a means of inverting the soil. With the ordinary plough a relatively small amount of soil disintegration is produced. The results with rotary cultivation in these and other experiments show that it does not produce a much finer tilth than other implements, as is commonly supposed. The essential feature of the tilth is that it is very much looser: in the Rothamsted experiments, a tilth nearly 6 in. deep is produced when the depth-shoe is set to give the tines an entry of $3-3\frac{1}{2}$ in. This loose tilth is, in the great majority of cases, an encouragement to early and more effective germination, and to the early growth of the plant. On the other hand, spells of heavy rain accentuate the natural tendency of the loose tilth to settle into a hard unkindly compactness, and the later stages of growth are hindered, so that the yields at harvest do not usually reflect the initial superiority in the early growth of the plant.

Fig. 3 and the numerical data from which it was drawn give five percentage numbers for each form of cultivation under test. It is often

convenient to replace these numbers by a 'single-value' giving an approximate measure of the total fragmentation. For this purpose a surface factor can be used which gives a rough measure of the total surface of the soil fragments. The lumps are assumed to be cubical, and the average length of side in any fraction is taken as midway between that sieve-aperture and that of the next larger sieve. The cube sides are then approximately 0.05, 0.2, 0.4, and 1.0 in., whilst for the pieces on the largest sieve an arbitrary value of 2 in. is assigned, since their contribution to the total surface area is small.

A simple calculation shows that the surface area of a given fraction is proportional to the percentage weight of that group divided by the appropriate cube side. The sum of the surface areas for each fraction represents the single-value figure for the complete sample. It will be observed that the single value is weighted in the direction of the smaller-sized particles.

Finally, the size of sieves chosen as most suitable for moist temperate conditions and medium to heavy soil may need modification for other soils and climates. The main point to observe is that unduly fine meshes should not be chosen, since the idea of the measurement is to obtain a value for the mechanical disintegration produced by the cultivation implement. Apart from this, the work of sieving with fine meshes would occupy too long a time to be fitted easily into the design of most cultivation experiments.

(Received April 7, 1933)

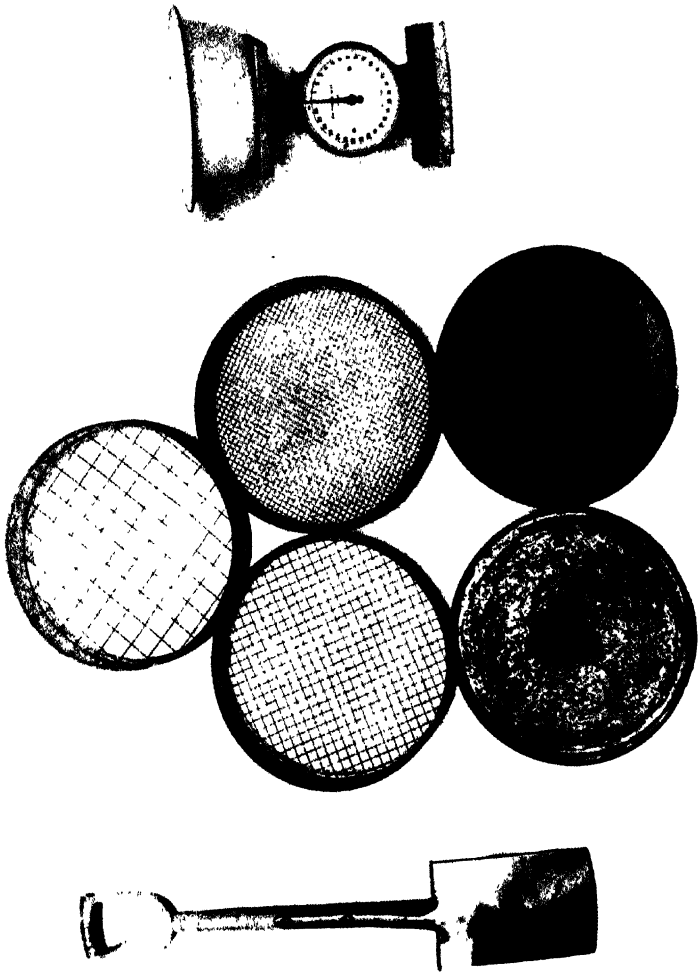


FIG. 2. EQUIPMENT FOR SIEVING TESTS
Scale: blade of spade 12 inches long

THE SIGNIFICANCE OF CERTAIN "SINGLE VALUE" SOIL CONSTANTS¹.

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MUCH attention has recently been paid to the rapid characterisation of soils, particularly by soil surveyors, who have often to map large areas rapidly and economically. One method of characterising a soil is by a series of its physical properties, usually called single value soil properties, and for field survey purposes particularly, by a series of properties easy and rapid to measure. It is thus desirable to devise criteria which will select from all the possible physical measurements on soil, just those that will give the maximum amount of information relevant to the problem in hand. The object of this paper is an examination of the criteria available, and for this purpose a detailed statistical examination of the physical properties of the 64 Natal soils used by Coutts was undertaken. The method employed is to discover what type of information is given by each physical constant, so that those constants can be picked out which give the maximum amount of independent information about the soil.

THE DATA EMPLOYED IN THIS ANALYSIS.

Practically all the data used in this analysis were supplied by Coutts, much of it already being published (2, 3, 4). Only 64 of his 66 soils were used, since not all the data were available for soils Nos. 47 and 51 of paper II (2), as insufficient material was available for all the constants to be determined. The following data have been used:

The mechanical analysis, the loss on ignition, the moisture content at 50 per cent. relative humidity, the moisture content at the sticky point, and the Keen-Raczkowski box data using the original boxes. All this material is published in paper II (2).

The Keen-Raczkowski box data using the modified boxes, given in paper III (3).

¹ The author is much indebted to Mr J. R. H. Coutts, University College, Pietermaritzburg, Natal, who has supplied him with unpublished data and details of experimental methods, to supplement the published data referred to in the text. He also acknowledges Mr Coutts' assistance in preliminary discussions on the scope of the paper.

262 *Significance of Certain "Single Value" Soil Constants*

The moisture equivalent, the xylene equivalent and the density of the soil in paraffin given in paper VII(4).

Samples of each soil were boiled with hydrogen peroxide, filtered and dried, and the following unpublished data were available on these peroxide-treated soils:

Loss on ignition, the moisture content at 50 per cent. relative humidity, the moisture content at the sticky point, and the Keen-Raczkowski box data using the modified boxes.

Several new parameters were calculated from the primary Keen-Raczkowski box data, and some parameters previously calculated, but not published, have also been used. In addition, the "base exchange capacity" of these soils has been determined, using Schofield's⁽¹⁴⁾ potassium phosphate buffer method, in which the milli-equivalents of potassium removed from a phosphate buffer just below pH 7 by 100 gm. of soil is measured. As pointed out by Schofield, this is not exactly equivalent to the exchangeable base content at pH 7, because

- (1) the exchangeable sodium and potassium are not measured,
- (2) not quite all the exchangeable calcium and magnesium are precipitated by the phosphate,
- (3) some potassium appears to be removed from the solution as a complex phosphate.

For slightly acid soils the last two effects counterbalance each other. For neutral soils the exchangeable base content is under-estimated by about 10–20 per cent., while for very acid soils it is over-estimated by about the same amount. Since the Natal soils investigated range from acid to neutral, these two sources of error will be important.

LIST OF SYMBOLS USED IN THE FOLLOWING DISCUSSION.

- B*, the base exchange capacity of the soil, determined by Schofield's method;
- C*, the clay content, expressed by its ignited weight as a fraction of the air-dry soil.
- F*, the fine silt content, *i.e.* fine silt I and fine silt II of paper II(1).
- G*, the coarse silt content, *i.e.* silt of paper II(1).
- h*, the moisture content of the soil in equilibrium with a 50 per cent. relative humidity atmosphere.
- I*, the loss on ignition.
- J*, the imbibitional water.

¹ The author thanks Dr R. K. Schofield for placing this data at his disposal.

M , the moisture equivalent.

p , the different pore spaces determined from the Keen-Raczkowski box data.

S , the moisture content of the soil at its sticky point.

v , the different swellings determined from the Keen-Raczkowski box data.

w , the water held per 100 gm. of oven-dry soil in the Keen-Raczkowski box.

X , the xylene equivalent.

ρ , the density of the soil.

σ , the density of the soil-air system, as determined in the Keen-Raczkowski box.

A suffix p , as for example S_p , denotes that the parameter has been determined on the peroxide-treated soil, and a dash, as for example w' , that the box parameter has been determined from the short (modified) box data.

Coutts states that most of his soils come from within 50 miles of Pietermaritzburg, mostly from wattle-growing areas, so that it is possible the soils investigated were selected owing to their suitability for wattle cultivation, and were not evenly selected over the geographical area. This might mean that some of the soil relationships found are not fundamental but purely arbitrary ones necessary for wattle to grow well. One cannot entirely eliminate this possibility, though some results of Charlton's⁽¹⁾ for Burmese paddy soils make it appear very improbable, for they agree remarkably well with Coutts', as is shown in the following table:

Table I. *Comparison of some correlation coefficients of Burmese paddy soils and Natal wattle soils.*

	Burmese paddy soils		Natal wattle soils	
	Untreated (24 soils)	Peroxide-treated (22 soils)	Untreated (64 soils)	Peroxide-treated (65 soils)
r_{SI}	0.939	0.977	0.929	0.944
r_{Sh}	0.901	0.925	0.907	0.922
r_{SC}	0.725	0.803	0.738	0.811
r_{hI}	0.947	0.943	0.913	0.936
r_{hC}	0.884	0.816	0.773	0.794
r_{IC}	0.869	0.857	0.752	0.824

There seems to be no reason, therefore, for considering the relationships found hold only for wattle soils. Nor do the results apply to soils from one geological formation only, for the soils used appear to be

264 *Significance of Certain "Single Value" Soil Constants*

derived from several. The actual values of the soil constants are also fairly evenly distributed over their whole range of variation, as is shown for example by the following table for the distribution of values of S .

Table II. *Distribution of the values of the sticky point S .*

Range in which S lies (%)	Below 30	30-40	40-50	50-60	Above 60
Number of soils with sticky points in the range	8	16	20	10	10

It thus seems fair to conclude that the results obtained are genuine relationships between soil properties and are not due either to systematic or to limited sampling. But since all the soils came from a limited geographical region, the relationships are only expected to be type relationships, and though they seem to be valid for other types, as is shown from a comparison with Charlton's results, they are not necessarily valid for a mixture of widely different soil types, as for example in the selection used by Keen and Coutts⁽⁹⁾.

STATISTICAL METHODS EMPLOYED.

In this paper the multiple regression analysis has been used, and for this purpose multiple correlation coefficients have usually been computed. If $\Sigma (y - \bar{y})^2$ is the sum of squares of a parameter y from its mean value \bar{y} , summed over all the values of y under discussion, and if Y is the value of y computed from the regression equation

$$Y = \alpha + \beta_1 x_1 + \beta_2 x_2,$$

then the multiple correlation coefficient of y with the variates x_1 and x_2 , namely $R_{y.x_1x_2}$, is defined by the equation

$$1 - R_{y.x_1x_2}^2 = \frac{\Sigma (y - Y)^2}{\Sigma (y - \bar{y})^2},$$

$1 - R_{y.x_1x_2}^2$ gives the proportion of the total variance of y unaccounted for by its dependence on x_1 and x_2 . If a third variate, x_3 , is now added, and the variance of y accounted for by this new multiple regression equation is $R_{y.x_1x_2x_3}^2$, the additional proportion of the total variance of y accounted for by x_3 over and above that accounted for by x_1 and x_2 is

$$R_{y.x_1x_2x_3}^2 - R_{y.x_1x_2}^2.$$

This quantity will nearly always be positive, but it does not necessarily imply that the variate x_3 is of any importance, for adding another variate will be expected to reduce the total residual variance $\Sigma (y - Y)^2$. To test if an added variate, x_3 , has reduced the residual variance of y

more than it would be expected to do if it were in fact uncorrelated with y , the Fisher z -test must be applied. If there are n independent sets of observations on each of the variates, each set is said to possess n degrees of freedom, for no one observation can be calculated from the others. But if y is calculated from the regression equation

$$Y = \alpha + \beta_1 x_1 + \beta_2 x_2,$$

then $\Sigma (y - Y)^2$ contains only $n - 3$ degrees of freedom, for the n quantities $(y - Y)^2$ are now related by the three equations used to determine the constants α , β_1 and β_2 . If x_3 had no significant linear relationship with y over and above that which it may have through x_1 and x_2 , fitting a constant β_3 to the regression equation would reduce by unity the number of degrees of freedom on which the residual variance is based, and would therefore be expected to reduce the proportion of the total variance of y unaccounted for by

$$\frac{1}{n-3} (1 - R^2_{y \cdot x_1 x_2}).$$

Fisher splits up $(1 - R^2_{y \cdot x_1 x_2})$ containing $n - 3$ degrees of freedom into two parts, one giving the reduction of variance due to introducing x_3 into the regression equation, namely $R^2_{y \cdot x_1 x_2 x_3} - R^2_{y \cdot x_1 x_2}$, containing one degree of freedom, and the other giving the residual variance of y unaccounted for after x_3 has been fitted, namely $1 - R^2_{y \cdot x_1 x_2 x_3}$ containing $n - 4$ degrees of freedom. His z -test consists in simply comparing

$$\frac{1}{n-4} (1 - R^2_{y \cdot x_1 x_2 x_3}) \text{ with } R^2_{y \cdot x_1 x_2 x_3} - R^2_{y \cdot x_1 x_2}.$$

If this latter quantity is significantly greater than the former, as judged by this test, then x_3 is significantly correlated with y and is said to add significantly to the multiple regression equation.

The other test used in this paper is one to decide if the residual variance of y , after a set of independent variates, say x_1 and x_2 , have been fitted, is sufficiently small to be due solely to errors in the determinations of y , x_1 and x_2 . Most of the data considered in this paper are the means of two determinations. Let x_1' and x_1'' be two duplicate determinations of x_1 on a given soil, so that $x_1 = \frac{1}{2} (x_1' + x_1'')$, and let $V(x_1)$ be the variance of x_1 , due to errors of experiment, then

$$V(x_1) = \frac{1}{4n} \Sigma (x_1' - x_1'')^2,$$

where the summation is taken over the n soils studied. If now

$$Y = \alpha + \beta_1 x_1 + \beta_2 x_2,$$

266 *Significance of Certain "Single Value" Soil Constants*

then the variance of Y due to errors in the determination of x_1 and x_2 is

$$V(Y) = \beta_1^2 V(x_1) + \beta_2^2 V(x_2),$$

provided that, for each soil, the experimental errors made in the determination of x_1 are independent of those made in x_2 . If the mean residual variance of y from the above regression equation is

$$V(y.x_1x_2) = \frac{1}{n-3} \sum (y - Y)^2,$$

the portion of this due to errors in the determination of y , x_1 and x_2 is

$$V(y) + V(Y) = V(y) + \beta_1^2 V(x_1) + \beta_2^2 V(x_2);$$

again provided that for each soil the experimental errors made in the determination of y are independent of those made in the determinations of x_1 and x_2 , so that to decide whether or not y is completely determined by the variates x_1 and x_2 within the limits of experimental error, this variance must be compared with $V(y.x_1x_2)$ by means of the z -test.

For the result of this comparison to be valid, three conditions must be fulfilled:

(1) For a given soil, the experimental errors in the determination of y , x_1 , x_2 and x_3 should be independent of each other.

(2) The mean value of $(x_1' - x_1'')^2$ should be independent of the value of x_1 , that is, the errors to which a variate is subject must be independent of the absolute value of that variate.

(3) There should be no systematic errors occurring between the " x " values for different soils, that is, each $(x_1' - x_1'')$ must be expected to contain all the sources of error likely to occur in any determination of x_1 .

For the data under discussion, the first condition is always fulfilled provided that the regression equation does not contain more than one box constant, since these are the only sets of constants determined on the same sample of soil. The second condition is probably fulfilled, while the third is almost certainly not. The duplicate determinations of a variate were usually carried out simultaneously, so that any sources of systematic error will be excluded from the experimentally determined error, the three main exceptions being the moisture and xylene equivalents and the base exchange capacity. The result of this is that $V(y) + V(Y)$ will be under-estimated, so if it happened that the residual variance of y from the regression equation could all be accounted for by the experimental variance, this result would undoubtedly be valid, but if it happened that the residual variance was rather greater than

could be accounted for by experimental error, one could not conclude that some other important factor had been left out from the regression equation, as it might be due to this under-estimation of the experimental error.

The details of the significance tests will not in general be given, as the primary data needed to make them will usually be included in the tables. In every case when any discussion is undertaken about a difference, that difference is significant. The details of the computation of the multiple correlation coefficients and of the regression coefficients are given in the Appendix at the end of the paper.

THE INTERPRETATION OF THE BOX PARAMETERS.

A method of obtaining a series of soil constants by means of swelling and water adsorption measurements on soils was put forward by Keen and Raczkowski (10). The method consists in filling a brass box which has a perforated bottom with finely divided soil, placing the box in a shallow depth of water, so that water can rise in the soil from below, and after an interval of time removing the box from the water, weighing it and determining the weights of both the soil and water left in the box, and the soil and water that has swelled above the original level of the box. This method has been used extensively by certain Empire workers, notably Marchand (12) in the Transvaal, Coutts (2) in Natal, Hines (8) in Queensland. The method appears to be suited to Empire conditions, and it is therefore important to discover what type of information it supplies.

The first parameter to be discussed is the weight of water held per 100 gm. of oven-dry soil. This quantity, w , is not constant throughout the box, but depends on the height of the layer under consideration from the bottom. In the boxes used by Coutts, of heights 1 in. and $\frac{5}{8}$ in. respectively, the water content of the uppermost soil layer, *i.e.* that which had swollen above the level of the box, is always higher than in the soil remaining in the box. For the 64 soils used, the following table gives the mean values for w_s , the expelled soil, called the surplus soil, w_r , the soil left in the box, called the residual soil, and w , for all the soil in the box.

Table III. *The mean value of w for the 64 Natal soils.*

	Tall boxes, untreated soil		Short boxes, peroxide-treated soil
Surplus soil w_s	60.29	60.91	50.60
Residual soil w_r	43.24	49.94	45.09
Whole soil w	44.19	51.09	45.63

268 *Significance of Certain "Single Value" Soil Constants*

Unfortunately from the method of obtaining the data no very accurate estimate of the errors in w is possible, since duplicate determinations were always made at the same time. The difference between duplicates will exclude all systematic errors, such as differences in the oven-drying, which may easily be considerable. The following table gives the variance of the mean of duplicate determinations, each entry being based on 64 comparisons, and thus on 64 degrees of freedom.

Table IV. *Variance of the means of duplicate determinations of w .*

	Tall boxes, untreated soil		Short boxes, peroxide-treated soil
w_s	1.409	1.529	0.513
w_r	0.306	1.354	0.474
w	0.365	1.075	0.479

w and w_r seem to be most accurately determined in the tall box, but it holds about twice the weight of soil and water that the short boxes hold. w_s is measured on about the same weight of soil in each box and appears to be subject to larger errors than w or w_r , as would be expected, since it is measured on much less soil. w_s or w_r measured in the tall box cannot be calculated within experimental error from w_s' or w_r' , the corresponding quantities for the short box, for, using the equation

$$W_s = \alpha + \beta w_s' \quad \text{or} \quad W_r = \alpha + \beta w_r',$$

the regressional variance of w_s ,

$$\frac{1}{2} \Sigma (w_s - W_s)^2,$$

is greater than

$$V(w_s) + \beta^2 V(w_s'),$$

the variance due to random experimental errors, as is shown in Table V. Nor can any of the three w_s be computed from the corresponding w_r , although, as is also shown in Table V, the values of β in the linear

Table V. *The accuracy of the linear regressional equations connecting two w 's.*

$w_i = \alpha + \beta w_j$	α	$s(\alpha)$	β	$s(\beta)$	$\frac{1}{2} \Sigma (w_i - W_i)^2$	$V(w_i) + \beta^2 V(w_j)$
$w_s = \alpha + \beta w_r$	13.52	0.476	1.082	0.0432	14.47	1.77
$w_s' = \alpha + \beta w_r'$	10.62	0.430	1.007	0.0322	11.88	3.33
$w_{sp} = \alpha + \beta w_{rp}$	6.54	0.232	0.977	0.0167	3.44	0.97
$w_s = \alpha + \beta w_{sp}$	5.09	0.398	0.906	0.0300	10.19	2.67
$w_r = \alpha + \beta w_{rp}$	1.95	0.385	0.827	0.0301	9.47	1.52

regression equations do not differ significantly from unity. The obvious deduction to make from this result is that the difference between the mean moisture contents of the surplus and residual soil depends solely

on the height of the box and not on the soil, but this deduction is not of general validity, for, using only the short boxes, this difference is much larger for the natural untreated soils, 10.62 ± 0.43 , than for the peroxide-treated soils, 6.54 ± 0.23 .

A further analysis of w_s can easily be made. The variance of the mean of duplicate determinations of w_s is 1.409 and 1.529, based on 63 and 70 pairs of observations, for the tall and short boxes respectively, using untreated soil, and these two estimates of variance do not differ from each other significantly as judged by Fisher's *z*-test. Using the full number of differences available, the mean value of $(w_s' - w_s)$ is 0.788 per cent. with a standard deviation of 0.202 per cent. based on 73 differences. But the variance of each individual $(w_s' - w_s)$ from the mean value of $\Sigma (w_s' - w_s)^2$ is 11.97, which is much greater than the variance 2.938 due to divergences between duplicates in the two series. Hence

- (1) the experimental variance of w_s is independent of the box used,
- (2) the variance of $(w_s' - w_s)$ is much greater than the variance of w_s or w_s' alone,
- (3) w_s' is significantly greater than w_s .

As already pointed out, no accurate variance test can be made because of unknown systematic errors, but some idea of their magnitude can be obtained. The weight and moisture content of air-dry soil put in the box is known, as also is the weight of oven-dry soil that has swelled above the box and the weight of oven-dry soil left in the box. These last two added together should give the oven-dry weight of air-dry soil initially in the box. Similarly for the wet soils, the difference between the sum of the weight of wet residual and wet surplus soil should equal the total weight of wet soil. For convenience of presentation, these observed differences have been put into a distribution table (Table VI), which shows the number of times a given difference occurs in each set of experiments. The figures in *italics* give the number of observations accounted for by duplicates agreeing within 0.1 gm., and a minus sign in the first column of the table means that the sum of the components is greater than the original weight of the whole soil.

Evidently the weights of the components are usually about 0.1 gm. lighter than the weight of the original soil, which may be due to loss of soil during slicing, or evaporation or drainage of water from the top layers. But there are a relatively large number of bad errors.¹ Calling

¹ In the box experiment large errors of the type discussed in this paper may occur, which appear to be inherent in the present technique.

270 Significance of Certain "Single Value" Soil Constants

Table VI. *Distribution of the differences between the bulk and the component weights of wet and dry soil in the box.*

Differences in gm. between	Wet soil				Dry soil			
	Untreated		Peroxide- treated		Untreated		Peroxide- treated	
	Tall	Short	Short	Total	Tall	Short	Short	Total
- ∞ and -0.5	6 —	5 —	2 —	13 —	3 —	4 —	4 —	11 —
-0.5 „ -0.2	3 —	2 —	— —	5 —	2 —	1 —	1 —	4 —
-0.2 „ -0.1	— —	— —	1 —	1 —	4 —	3 —	5 —	12 —
-0.1 „ 0.0	5 —	8 —	2 —	15 —	7 —	5 —	19 —	31 —
0.0 „ 0.1	57 —	65 —	11 —	133 —	24 —	61 —	42 —	127 —
0.1 „ 0.2	46 —	39 —	52 —	137 —	25 —	49 —	26 —	100 —
0.2 „ 0.3	9 2	12 2	25 16	46 20	24 20	6 4	13 10	43 34
0.3 „ 0.4	— —	3 —	17 10	20 10	9 8	5 2	6 2	20 12
0.4 „ 0.5	— —	1 2	6 4	7 6	11 6	3 2	2 —	16 8
0.5 „ 1.0	1 —	3 —	8 —	12 —	18 16	4 2	9 6	31 24
1.0 „ ∞	6 —	3 —	3 —	12 —	6 4	— —	— —	6 4
No. of differences	133 2	141 4	127 30	401 36	133 54	141 10	127 18	401 82
No. outside -0.5 to +0.5	13 —	11 —	13 4	37 6	27 20	8 2	13 6	48 28
Mean, omitting above	0.089	0.093	0.195	—	0.114	0.101	0.089	—

all differences greater than 0.5 gm. bad, no less than 10 per cent. of the observations fall into this class. It is impossible to say what the cause of the large losses is; a few are undoubtedly weighing errors, but a large proportion are systematic, that is, they occur in duplicates which agree to within 0.1 gm. This effect is not a soil property, since soils giving large differences in one type of box may give only small differences in the other. There is no evidence, moreover, that the errors depend on the weight of the surplus or residual soil. To judge the seriousness of these errors in computing w_s or w_r , it should be noted that the weight of surplus soil varies from 3 to 12 gm. for the wet soil and from 2 to 7 gm. for the dry soil, while the weight of residual soil varies from 70 to 100 gm. wet and 40–80 gm. dry in the tall boxes and 40–60 gm. wet and 25–50 gm. dry in the short boxes. It is not known whether the above errors affect both the weights of the surplus and the residual soil. Obviously a given error in the determination of the weight of surplus water or surplus soil affects w_s much more than that same error in the determination of the weight of residual water or residual soil affects w_r . Examining the table in detail, it is evident that for the tall boxes the differences for the wet soil are small, while for the dry soil they are much larger but mainly systematic. Out of the 133 differences available for the wet soil only

16 are greater than 0.2 gm., of which two occur in duplicates agreeing to within 0.1 gm., while for the dry soil there are 68 such differences, of which 54 are in closely agreeing duplicates. In the series using the short boxes, there are more large differences in the wet soil than for the tall boxes, but fewer for the dry soil. The tall boxes give a greater variability of the differences for the dry soil than the short, which is not due to imperfect drying of the large mass of residual soil in the boxes, for the effect observed is in the opposite direction. It might be due to the incomplete drying of the small samples used to determine the air-dry moisture content of the original soil. In the tall boxes there are about 1–3 gm. of air-dry moisture, so that an error of 0.5 gm., as has several times occurred, would imply that the air-dry moisture figure was 15–20 per cent. too low. This error is so large that it is difficult to believe that it can be the complete explanation of these results.

The next question is to discover what type of information about the soil properties is contained in w . The following table gives the correlation coefficients of w , taken on the whole soil, with certain other soil parameters.

Table VII. *Correlation coefficients of w with other soil parameters.*

Box and soil used	Parameter						
	B	h	S	I	C	M	X
Tall box, untreated soil	0.9544	0.9399	0.9398	0.9147	0.7451	0.9527	0.8947
Short box, untreated	0.9699	0.9459	0.9433	0.9383	0.7234	0.9222	0.8416
Short box, peroxide-treated	—	0.9556	0.9723	0.9623	0.8136	—	—

This table shows that w is very closely related to B , h , S and I , and can barely be said to measure a different property from them. Of the three ways of measuring w , namely using w , w_r , or w_a , that measured on the residual soil, w_r , appears to be a somewhat better parameter to determine, as judged by the closeness of the relation with these others. This is shown in the following table.

Table VIII. *Comparison of the correlation coefficients of different w 's.*

	Bw correlations		hw correlations		
	Tall box	Short box	Tall box	Short box	Short box, peroxidized soil
w	0.9544	0.9699	0.9399	0.9459	0.9556
w_r	0.9510	0.9704	0.9420	0.9496	0.9502
w_a	0.9579	0.9662	0.9141	0.9223	0.9441

272 *Significance of Certain "Single Value" Soil Constants*

These correlations, though high, cannot be considered as exact, for even the value of B predicted from the w regression disagrees with the observed values more than can be attributed to experimental error. The regressional variance of B from the equation $B = \alpha + \beta w_r$ is 2.894 per degree of freedom, which is significantly greater than 0.736, the amount attributable to experimental error.

In concluding this section, the main points so far brought out are:

(1) that of the three ways of measuring w , that using the residual soil alone seems to be the most advantageous, but it really is immaterial which is used;

(2) the short box is definitely better than the tall, though even this may be illusory owing to certain large systematic errors which seem to have crept into the primary data for the tall boxes;

(3) w measures a property very closely correlated with B , h , I and S , though the divergence from perfect correlation is more than can be accounted for by random experimental errors.

The pore space.

Keen and Raczkowski defined the pore space, p , as the weight of water held by 100 c.c. of the soil-water system in the box, and measured it by dividing the weight of water in the residual soil by the volume of the box. Thus, whereas w is the weight of water held by 100 gm. of dry soil, p is the weight of water held by 100 c.c. of the soil-water system. But, as Marchand⁽¹²⁾ pointed out, there is another definition of pore space equally worth considering, namely the ratio of the volume of air in the soil to the volume of the soil-air system. The aim of these two definitions is evidently different. Ideally, the first is required to measure the maximum water-holding capacity and the second to measure the maximum air-holding capacity of the soil. Not all the water taken up by the soil is free water, for some is bound to or imbibed by the colloidal material present, and should not be considered as pore-space water. Thus these two ideal pore-space definitions should differ by the volume of this imbibitional water. But in an actual box experiment several complications occur; for example, as Keen and Raczkowski pointed out, not all the air in the soil is displaced by the rising water; nor is the density of the imbibitional water unity. There is, as yet, no simple method available to determine from box measurements alone the volume of the air left entrapped, and this error vitiates all pore-space determinations carried out under atmospheric pressure. In comparing these definitions, moreover, the packing of the soil must be con-

sidered, for all the soil used in the experiment is ground so that as much as possible passes a 100-mesh sieve, the fraction passing being then mixed as well as possible with the coarse sand fraction left on the sieve. This breaking up of the soil crumbs introduces the state of packing of the individual soil particles in the box as a subsidiary variable. Thus the air-pore space of this system is somewhat artificial, having no direct relation with the air-holding capacity of the soil in the field, whilst the maximum water-holding capacity may still be a fairly definite physical quantity.

The method used to determine the water-pore space of the soil has already been given. The air-pore space is obviously equal to

$$\frac{\frac{1}{\sigma} - \frac{1}{\rho}}{\frac{1}{\sigma}} = \frac{\rho - \sigma}{\rho},$$

where ρ is the density of the individual soil particles and σ is the density of the soil-air system. An estimate of both ρ and σ can be made from the box experiment, and before any further comparison is made between the different-pore spaces, a short examination of the soil densities so determined will be made. σ , the density of the soil-air system, is determined by dividing the weight of air-dry soil packed in the box by the volume of the box, and ρ , the density of the soil particles, by dividing the weight of soil left in the box by the volume of the box less the weight

Table IX. *The distribution of differences between duplicate determinations of ρ and σ .*

Difference between duplicates lying in the ranges	σ				ρ			
	Untreated soil		Per- oxidized soil		Untreated soil		Per- oxidized soil	
	Tall boxes	Short boxes	Short boxes	Sum	Tall boxes	Short boxes	Short boxes	Sum
0.00-0.01	7	26	17	50	6	7	13	26
0.01-0.02	15	26	16	57	2	7	4	13
0.02-0.03	11	12	9	32	4	8	5	17
0.03-0.04	9	6	8	23	2	4	12	18
0.04-0.05	3	—	5	8	2	8	4	14
0.05-0.10	18	1	8	27	18	22	9	49
0.10-0.15	4	—	1	5	12	8	9	29
0.15-0.20	—	—	—	—	5	2	5	12
Greater than 0.20	—	—	—	—	16	4	3	23
No. of duplicates	67	71	64	202	67	70	64	201
No. of duplicates < 0.05	45	70	55	170	16	34	38	88
No. of duplicates > 0.10	4	0	1	5	33	14	17	64

274 *Significance of Certain "Single Value" Soil Constants*

of water in the box. Thus ρ should measure the density of the soil particles immersed in water. The following table gives the distribution of the differences between duplicate determinations of ρ and σ in the different series.

The values of σ vary from 1.0 to 1.6 and of ρ from 1.9 to 2.6. Evidently ρ , and to a lesser extent σ , are subject to comparatively large errors. This is not inherent in the soil, for the distribution of differences between duplicate determinations of the density made by immersing a soil with paraffin in a vacuum is quite different, as is shown below.

Table X.

Difference between duplicates lying in the range	No. of duplicates lying in the given range
0.00-0.01	42
0.01-0.02	16
0.02-0.03	4
0.03-0.04	2
No. of duplicates	64

Now it is known that the density of a soil is higher in water than in paraffin if precautions are taken to exclude air, but in these experiments the densities of the soils in water, determined in the boxes, are usually less than the densities of the soils in paraffin. Table XI gives the distribution of certain of the differences between densities determined on the same soils. In every case the individual densities are the means of two determinations.

Table XI. *A comparison of different methods used to determine the soil density.*

Difference between densities between	ρ paraffin - ρ water			Difference between densities between	σ_{tall} - σ_{short}
	ρ_w from tall boxes	ρ_w from short boxes	ρ_{tall} - ρ_{short}		
-0.3 and -0.2	—	—	3	0.0 - 0.05	8
-0.2 „ -0.1	—	2	3	0.05-0.10	33
-0.1 „ 0.0	7	2	6	0.10-0.15	16
0.0 „ 0.1	18	6	9	0.15-0.20	6
0.1 „ 0.2	24	3	14	0.20-0.25	1
0.2 „ 0.3	12	15	13	No. of differences	64
0.3 „ 0.4	2	19	9		
0.4 „ 0.5	1	15	5		
0.5 „ 0.6	—	2	2		
No. of differences	64	64	64		

For the tall boxes the soil density is typically between 0.0–0.3 units too low, while for the short boxes it is between 0.2–0.5. Further, the tall boxes were tighter packed than the short, for the density of the soil-air system is 0.05–0.15 unit higher in the tall than in the short boxes. Also, as was shown in Table IX, the variability of the individual values of the soil density, ρ , was smaller in the short than in the tall box experiments. It is not possible, unfortunately, to give any definite explanation of these results, as the two factors involved, namely the height of the box and the tightness of packing, cannot be separated. So that two possible interpretations can be put forward, either

(1) the shorter the boxes the more reproducible are the determinations of the densities;

(2) the tighter packed the soil the less air is entrapped, so the higher the density;

or (1) the tighter the packing the more reproducible are the determinations of the densities;

(2) the taller the soil column the less air is entrapped.

There are no criteria available in this experiment to decide between these two interpretations.

Turning now to the actual determinations of the pore space, three different definitions will be considered, namely

(1) the Keen-Raczkowski parameter p_1 , defined as the weight of water held per 100 c.c. of the box;

(2) the estimate of the true air-pore space, p_2 , made by using the the box parameters and calculated from $p_2 = \frac{\rho - \sigma}{\rho} \times 100$, where ρ is the apparent density of the soil in water determined from the box;

(3) the true air-pore space p_3 , defined as the volume of air held per 100 c.c. of the soil-air system, and calculated as $p_3 = \frac{\rho_p - \sigma}{\rho_p} \times 100$,

where ρ_p is the density of the dry soil determined under vacuum in specific gravity bottles using paraffin as the wetting liquid. This is not a box constant, for although σ is determined in the box, ρ_p is not. Table XII gives the mean value of each of these three p 's for the 64 soils, together with the variance of the means of duplicate determinations.

The height of the box has only a small influence on the values of p_1 and p_2 ; its influence on p_3 is due to the tighter packing of the soils in the tall boxes, so that the air-pore space is naturally less than in the short boxes. The small influence of height on p_1 and p_2 is surprising, for

276 *Significance of Certain "Single Value" Soil Constants*

w_r , the weight of water per unit weight of soil left in the box, is definitely smaller in the tall boxes than in the short, yet the weight of water per unit volume of the box is almost the same for both. The difference between these two results must depend on the different amounts of air entrapped in each case, but the experiment supplies no criteria to decide if this compensation is a chance effect due to the particular conditions of the experiment, or if it is a genuine effect.

Table XII. *The mean values of the p 's and the accuracy of their determination.*

	Untreated soil, tall boxes			Untreated soil, short boxes			Peroxided soil, short boxes	
	p_1	p_2	p_3	p_1'	p_2'	p_3'	p'_{1p}	p'_{2p}
Mean	50.16	43.94	46.91	51.05	42.29	50.60	49.20	41.80
Variance	0.860	1.086	0.916	0.675	1.080	0.167	0.452	0.884

As noted by Coutts(3), the value of p_1 is not quite independent of the box used, for the difference between p_1 and p_1' is greater than can be accounted for by the divergence between duplicate determinations of p_1 and p_1' , and, even if p_1 is assumed to be related to p_1' by the equation

$$p = \alpha + \beta p_1',$$

the divergences between the calculated and the observed values of p_1 are still outside experimental error. Considering all the different p 's, Table XIII shows that if any p is calculated from any other p by means of a linear regression equation, the differences between the observed and calculated values do not lie very far outside the limits of variation between duplicate determinations, as is shown by comparing the fifth column of Table XIII which gives the regressional variance per degree of freedom, and the sixth column which gives the experimental variance. The values of α , together with their standard deviations, are also given, and it is evident there is no justification for assuming α must be zero.

Table XIII. *The accuracy of the linear relations connecting the various p 's.*

$p_i = \alpha + \beta p_j$	α	$\sigma(\alpha)$	β	$\frac{1}{2} \Sigma (p_i - \pi_i)^2$	$V(p_i) + \beta^2 V(p_j)$
$p_1 = \alpha + \beta p_1'$	-4.120	0.292	1.063	5.425	1.623
$p_2 = \alpha + \beta p_2'$	-2.181	0.300	1.091	5.772	2.371
$p_3 = \alpha + \beta p_3'$	-0.231	0.218	0.932	3.036	1.111
$p_1' = \alpha + \beta p_2'$	-2.195	0.202	1.259	4.070	2.388
$p_1' = \alpha + \beta p_3'$	-3.652	0.277	1.081	4.899	0.870
$p_2' = \alpha + \beta p_3'$	1.080	0.190	0.814	2.302	1.191

Turning now to the consideration of the type of information supplied by p , Table XIV gives the correlation coefficients of p with other soil parameters.

Table XIV. *Correlation coefficients of p_1 with other soil parameters.*

	w	h	S	I	B	C	M	X
p_1 , tall box, untreated soil	0.9483	0.9021	0.8925	0.8662	0.8969	0.7986	0.9088	0.8868
p_1' , short box, untreated soil	0.9511	0.9066	0.9131	0.9046	0.9267	0.7719	0.8998	0.8477
	w_p	h_p	S_p	I_p				
p'_{1p} , short box, peroxidized soil	0.9733	0.9303	0.9444	0.9420	—	0.8506	—	—

On comparing this table with Table VII, it is clear that p has a higher correlation coefficient with C than has w , they have about the same with X , but w has a higher one with the others. This result is true whichever definition of p is used, as is shown in Table XV.

Table XV. *Correlation coefficients of different p parameters with certain soil variates.*

		C	M	X	B	w	S
Short boxes, untreated:	p_1'	0.7719	0.8998	0.8477	0.9267	0.9511	0.9131
	p_2'	0.7139	0.8451	0.8504	0.8248	0.8714	0.8266
	p_3'	0.7882	0.8787	0.8726	0.8581	0.9043	0.8779
						w_p'	S_p
Short boxes, peroxide-treated:	p'_{1p}	0.8506	0.9543	0.9426	0.8575	0.9733	0.9444
	p'_{2p}	0.8102	0.9307	0.9344	0.8169	0.9116	0.8688

p_3 measures C and X more efficiently than does p_1 , which are just the two parameters measured more efficiently by p than by w . For the computing of the colloidal parameters, p adds no information not already contained in w , as is shown in Table XVI which gives the partial correlation coefficients of certain parameters with w , p being kept constant, and with p , w being kept constant.

Table XVI. *Some partial correlation coefficients of p and w .*

$\lambda =$	h	S	I	C	B	M	X
$\lambda p.w$	0.0994	0.0116	-0.0090	0.4349	-0.0858	0.0559	0.2706
$\lambda w.p$	0.6168	0.6529	0.5878	-0.0642	0.7398	0.6860	0.3663
$\lambda p'.w'$	0.0690	0.1552	0.1149	0.3932	0.0559	0.1900	0.2831
$\lambda w'.p'$	0.6417	0.5943	0.5913	-0.0546	0.7629	0.4927	0.2159
$\lambda_p p_p'.w_p'$	0.0598	-0.0297	0.0790	0.4343	—	—	—
$\lambda_p w_p'.p_p'$	0.5129	0.6657	0.5483	-0.1177	—	—	—

278 Significance of Certain "Single Value" Soil Constants

Thus in the prediction of h , S , I , B or M , if w is given, p adds no new information. In fact p is connected with these variates only through its close correlation with w . With C the opposite is true. C only seems to be correlated with w through p . But with X both w and p seem to be about equally important. Table XVII shows how this effect is modified by using different p 's.

Table XVII. *Partial correlation coefficients of p_1' , p_2' , p_3' and w' .*

	h	C	X
$\lambda p_1'.w'$	0.0690	0.3932	0.2831
$\lambda w'.p_1'$	0.6417	-0.0546	0.2159
$\lambda p_2'.w'$	-0.0669	0.2467	0.4415
$\lambda w'.p_2'$	0.8307	0.2949	0.3899
$\lambda p_3'.w'$	-0.0179	0.4547	0.4837
$\lambda w'.p_3'$	0.7994	0.0404	0.2519

All the colloidal parameters, such as h , are correlated with p only through w . Clay content seems to be determined by p and not by w unless p_2 is used, while X is more dependent on p than on w , particularly if the parameter p_3 is used.

Table XVIII is constructed to show whether each type of p contains different information, or whether each is measuring the same property with different degrees of closeness. The figures given show the additional proportion of the variance of the parameter λ accounted for by the addition of a second p to the regression equation, *i.e.* $R^2_{\lambda.p_1p_2} - r^2_{\lambda p_1}$. The letter after each entry represents the fundamental p parameter, the p_1 in the above example. A + signifies that the additional proportional of the variance accounted for is probably significant, for the probability that it could be zero lies between 5 and 1 per cent. as judged by Fisher's z -test, while a ++ signifies that the additional proportion of the variance accounted for is certainly significant, since the probability that it could be zero is less than 1 per cent.

Table XVIII. *Additional information supplied by a second p in conjunction with a first.*

λ	$p_1'p_2'$	$p_1'p_3'$	$p_2'p_3'$	$p_1'p_2'p_3'$
C	0.0006 (p_1')	0.0134 (p_3')	0.0040 (p_3')	0.0000 ($p_1'p_2'$)
M	0.0001 (p_1')	0.0159+ (p_1')	0.0045 (p_3')	0.0050 ($p_1'p_2'$)
X	0.0261+ (p_1')	0.0123 (p_3')	0.0096 (p_3')	0.0144++ ($p_1'p_2'$)
B	0.0147+ (p_1')	0.0001 (p_1')	0.0041 (p_3')	0.0000 ($p_1'p_2'$)
w'	0.0029 (p_1')	0.0049 (p_1')	0.0054 (p_3')	w_p' 0.0026 ($p_1'p_2'$)

The main point brought out by the above table is that all the p 's are measuring closely related properties, and all measure these properties in about the same way. As minor points, it is clear that p_2 adds very little, if any, information not contained in p_3 , and that p_1 and p_2 supply a certain amount of independent information about X . This latter point has been followed up a little. p_1 is more closely related to the colloidal properties of the soil than is p_2 , so that if X depended on a soil structure term and a colloidal term, p_1 might be measuring the colloidal term better than p_2 , while p_2 might be measuring the structure term better than p_1 ; on this hypothesis, if a good estimate of the colloidal term, as for example B or h , is used in conjunction with a p , p_2 would give a better regression than p_1 . Table XIX shows that this is actually so. The second and the fifth columns of the first part give the values of

$$1 - R^2_{X.hp} \text{ or } 1 - R^2_{X.Bp},$$

and the third and sixth columns give

$$(1 - R^2_{X.h}) - (1 - R^2_{X.hp})$$

and the corresponding difference for the $X.B$ correlations, which is the additional fraction of the total variance of X accounted for by the p under consideration.

Table XIX. *The influence of various p 's in increasing the $X.h$ and $X.B$ correlations.*

	$1 - R^2_{X.hp'}$	$\Delta p'$		$1 - R^2_{X.Bp'}$	$\Delta p'$
$X.h$	0.2593	—	$X.B$	0.3451	—
$X.hp_1'$	0.2337	0.0256	$X.Bp_1'$	0.2774	0.0677
$X.hp_2'$	0.1926	0.0667	$X.Bp_2'$	0.2405	0.1046
$X.hp_3'$	0.1889	0.0704	$X.Bp_3'$	0.2247	0.1204

p_3 , which is the best estimate of the air-pore space of the powdered soil, is thus seen to be the best parameter of the three to take with a colloidal parameter such as h or B . The main conclusions so far reached about the p 's are therefore:

- (1) all the p 's are closely correlated with the colloidal properties, but only through their close correlation with w ,
- (2) the non-colloidal information they add is probably concerned with the structure of the powdered soil,
- (3) the three estimates of the pore space give almost identical information about the soil structure, but the parameter p_3 , though not a real box constant, probably allows for the powdered structure better than the true box constants p_1 or p_2 , while p_2 probably allows for this better than p_1 .

The swelling parameters.

When a fine soil is packed in the box and wetted it swells, and this swelling will be measured by the ratio of some property of the swollen to some property of the initial or residual soil system. The processes involved in the swelling of the soil are complex, for as Keen and Raczkowski noted, soon after the box is placed in water and before the surface appears wet, the soil column contracts away from the walls of the box and sometimes develops cracks. The column then rises upwards, becomes wet and expands outwards filling the box again. This initial contraction of the soil system was traced entirely to water films drawing the soil particles together into a closer packing. For if a box is filled with a silt which shows no swelling, and placed in water, the column of silt contracts away from the walls of the box when damp, and when wet collapses, the saturated silt-water system occupying less volume than the original silt-air system. If more silt is added, so that the box is again full, and the whole dried, on a second rewetting very little if any contraction takes place, and on repeating the process of filling up, drying, and rewetting, all movement of the material ceases on wetting or drying. Similarly, if a box is filled with a dry finely divided soil and wetted with dry xylene, the soil shows the contraction phenomenon markedly, but there is practically no subsequent swelling. Thus the first stage in the volume changes taking place when a soil is wetted with water is a contraction, due to the water films bringing the loosely packed soil particles into a closer packing. Theoretically, if one could start with the soil-air system in an arrangement of closest packing, this initial contraction should not take place.

Turning to the factors causing the soil to swell, there appear to be three distinct ways in which the soil system can increase in volume.

(1) The individual colloidal particles on wetting become hydrated. They have the power of immobilising water either on or inside their surfaces, and so occupy a larger volume when saturated with water than when dry. The nature of this immobilisation of the water is irrelevant to the present discussion, and there appears to be no methods available for measuring either the volume of the saturated colloidal system or the amount of water immobilised. This factor causes the individual colloidal particles to increase in size.

(2) The water films formed in the pore space between two particles may be able to push them apart to allow some water films to join up. This would cause the system to take up a larger volume, and so swell, although the individual particles themselves would not have altered in size.

(3) As the water ascends the soil column it displaces air from inside the fine soil crumbs, and some of this air is entrapped between the particles and pushes them apart, so that the system as a whole swells, though the individual particles retain their original size.

Considering these factors in order, much of the swelling is certainly due to the binding of water by the soil colloids. The swelling of the bulk of the soil due to this cause is probably less than the total swelling of the individual particles, for the particles on swelling will probably alter the geometry of the pore space, and, in particular, reduce its volume. The second factor, if it exists, is only of very minor importance, for on wetting silts with water, or soils with dry non-polar liquids, as *e.g.* xylene, very little swelling, if any, occurs, although the liquid films are powerful enough to repack the original loosely packed soil, so that what little swelling does occur is probably due to immobilisation of the wetting liquid. The third factor of entrapped air is, however, of great importance, for if the soil is wetted under vacuum much less swelling takes place. An experiment with a Rothamsted subsoil, performed in both short and tall boxes, shows the effect of entrapped air on some of the box parameters. A rotary oil pump was used to obtain the vacuum, and the pressure inside the apparatus was much less than 1 mm. of Hg when the water was admitted.

Table XX. *The influence of entrapped air on the box parameters.*

	Tall boxes		Short boxes	
	Evacuated	Not-evacuated	Evacuated	Not-evacuated
w_r	48.95	44.26	51.84	49.94
w_s	53.69	52.34	59.74	56.15
σ	1.249	1.252	1.205	1.199
ρ	2.763	2.346	2.603	2.202
p_1	57.47	50.94	57.43	52.32
p_2	54.80	46.64	53.65	45.55
Weight of surplus soil	1.575	2.819	1.702	3.200
v_1	3.06	5.74	5.76	11.25
<u>surplus</u> <u>residual</u> soil	2.88	5.25	5.29	10.57
<u>surplus</u> <u>residual</u> water	3.21	6.20	6.10	11.83

This table shows that while the entrapped air decreases the experimental values for the pore spaces and density of the soil, it almost doubles the swelling.

The preceding discussion has shown that the swelling as measured on the bulk of the soil is a very complex parameter, and is the resultant of a series of swellings and contractions due to very diverse causes.

282 *Significance of Certain "Single Value" Soil Constants*

These various effects can at least partially be disentangled, for it should be possible to pack the soil in the boxes in closest packing so that, on wetting, no contraction of volume takes place. One might, for example, wet the soil with dry benzene first, and let this do the arranging of the soil particles in closest packing. The benzene would not alter the structure of the soil in any way and could easily be removed in a low-temperature oven afterwards. Thus the bulk, if not all, of the initial contraction could either be eliminated or measured as required. The subsequent wetting with water could be done in the absence and in the presence of air, so an estimate of the volume of entrapped air could be made. But it is still improbable that the swelling measured after these two preliminary conditions had been observed would measure the volume of the water immobilised, which is probably the parameter most worth measuring, because the movement of the individual particles relative to each other alters the shape, and hence the volume, of the pore spaces between them. It does not seem possible, therefore, to measure any simple fundamental soil parameter from the observed swelling, although if proper precautions are taken a valuable estimate of some fairly fundamental parameter would be made. The matter is now under investigation in this laboratory.

Turning to Coutts' experimental data on the Natal soils, in which no precautions against the changes in volume due to repacking or the entrapping of air were taken, it does not seem likely that any of the swelling parameters that can be computed from his observations will be measuring simple fundamental properties of the soil, but the following have been examined in some detail:

$$v_1 = \frac{\text{volume of surplus soil} + \text{volume of surplus water}}{\text{volume of the box}},$$

$$v_2 = \frac{\text{weight of surplus soil}^1}{\text{weight of residual soil}},$$

$$v_3 = \frac{\text{weight of surplus soil}}{\text{initial weight of soil}},$$

$$v_4 = \frac{\text{weight of surplus water}}{\text{volume of box}},$$

$$v_5 = \frac{\text{weight of surplus water}}{\text{weight of residual water}},$$

$$v_6 = \frac{\text{weight of surplus water}}{\text{total weight of water}}.$$

¹ This parameter has not been investigated in the present paper.

For the computation of v_1 , the volume of surplus soil is found by dividing the weight of surplus soil by its density, as determined in the box experiment, while the volume of surplus water is replaced by the weight of surplus water. The value of v_1 does not alter very much with changes in the volume of surplus soil, so only a small difference is made if the soil density, as measured in paraffin in the absence of air, is used instead of the box density. The mean value, m , of the different v 's for the 64 soils, together with s , the standard deviations of the means of duplicate determinations are given in Table XXI. The columns headed s/m give the relative accuracy with which each parameter is measured.

Table XXI. *The accuracy of measurement of different v parameters.*

	Tall boxes, untreated soil			Short boxes, untreated soil			Short boxes, peroxide-treated soil		
	Mean	s	s/m	Mean	s	s/m	Mean	s	s/m
v_1	10.2	0.46	0.045	15.9	1.11	0.070	12.4	1.39	0.112
v_2	7.6	0.33	0.043	12.4	0.85	0.069	—	—	—
v_3	—	—	—	9.2	0.67	0.072	—	—	—
v_4	12.0	1.05	0.088	17.7	1.27	0.072	13.1	1.31	0.100
v_5	10.8	0.79	0.073	14.8	1.26	0.085	11.4	1.22	0.107

The first point to notice from the above table is the relatively large experimental errors involved in measuring these swellings. The standard deviation of the mean of two determinations seems to be about 7–10 per cent. of the mean itself, and is about the same whichever parameter is chosen. This large variability of the swelling data is probably due to variability in packing and in the amount of air entrapped.

The swelling parameters are most closely correlated with the base exchange capacity of the soil, though they are not so closely correlated with the soil parameters as are p or w .

Table XXII. *Correlation coefficients of v_1 with certain other soil parameters.*

Box, soil	h	S	I	w	p	C	B	M	X
Tall, untreated	0.8198	0.8440	0.8075	0.8398	0.7485	0.5723	0.8711	0.7703	0.6177
Short, untreated	0.7794	0.7597	0.7561	0.8118	0.7681	0.5433	0.8223	0.6720	0.4999
	h_p	S_p	I_p	w_p'	p_p'				
Short, peroxidized	0.5700	0.6509	0.5545	0.6215	0.5918	0.5124	—	—	—

A swelling parameter by itself is thus of very limited value for predicting any of the other variates considered, but it can add considerably to the accuracy of some predictions, as is shown in Table XXIV, which

284 Significance of Certain "Single Value" Soil Constants

gives the increased proportion of the variance of a dependent variate accounted for when v_1' is added to the independent variate. Thus the entry in the column headed S and the row B is

$$(1 - R_{S.B}^2) - (1 - R_{S.Bv_1'}^2).$$

Table XXIII. *Correlation coefficients of different v parameters with B , M and X .*

	Tall boxes, untreated soil			Short boxes, untreated soil		
	B	M	X	B	M	X
v_1	0.8711	0.7703	0.6178	0.8223	0.6720	0.4999
v_2	0.8123	0.7599	0.6197	0.8262	0.7101	0.5674
v_3	—	—	—	0.8982	0.7705	0.6138
v_4	0.7688	0.6566	0.4944	0.8019	0.6417	0.4567
v_5	0.7533	0.6433	0.4835	0.8080	0.6362	0.4587

Table XXIV. *Increased proportion of the total variance of the dependent variate accounted for by adding v_1' to the independent variate.*

Independent variate	Dependent variate							
	S	I	h	p_1'	w'	B	M	X
S	—	0.0060	0.0192	0.0131	0.0214	0.0270	0.0010	0.0378
I	0.0077	—	0.0186	0.0165	0.0245	0.0343	0.0017	0.0498
h	0.0070	0.0051	—	0.0096	0.0142	0.0145	0.0067	0.0744
p_1'	0.0083	0.0092	0.0169	—	0.0161	0.0298	0.0009	0.0557
w'	0.0001	0.0001	0.0004	0.0000	—	0.0036	0.0172	0.0986
B	0.0007	0.0001	0.0002	0.0001	0.0006	—	0.0186	0.0846
M	0.0396	0.0333	0.0443	0.0487	0.0673	0.0802	—	0.0369
X	0.1610	0.1443	0.1626	0.1580	0.2039	0.2326	0.0504	—

All the simple correlation coefficients of the variates in the above table, with the exception of the X correlations, are above 0.9, so that the proportion of the total variance of the dependent variate unaccounted for by the main independent variate is less than 0.20, but in only a few cases is it less than 0.10. The X correlations, with the exception of the $M.X$ correlation which is above 0.95, are less than 0.9. Ignoring M for the moment, the simplest interpretation of the above table is

(1) v' is truly correlated with B or w' , and contributes to the prediction of S , h , I , p' solely through this correlation;

(2) v' is truly correlated with X , and of all the variates considered only X and v' measure this second soil property.

The first result can probably be expressed by the statement that the volume of imbibitional water is proportional to the base exchange capacity of the soil; the second result probably implies that the amount

of repacking of the soil, or the amount of air entrapped by the soil, is due to some property related to the soil structure that also affects the xylene equivalent. The results for the prediction of the moisture equivalent from other variates is complex, and will not be discussed in greater detail here. It is, however, interesting to note that

$$\begin{aligned}
 1 - R^2_{M.B} &= 0.1690, & 1 - R^2_{M.Bv} &= 0.1667, & 1 - R^2_{M.Bv'} &= 0.1504, \\
 \text{giving} & & \Delta(v) &= 0.0023, & \Delta(v') &= 0.0186, \\
 1 - R^2_{M.w} &= 0.0925, & 1 - R^2_{M.wv} &= 0.0895, & 1 - R^2_{M.w'} &= 0.1495, \\
 & & & & 1 - R^2_{M.w'v'} &= 0.1323, \\
 \text{giving} & & \Delta(v) &= 0.0030, & \Delta(v') &= 0.0172.
 \end{aligned}$$

showing that this curiously high contribution to the *MB* and *Mw* regressions is a property of v' , that is the swelling determined in the short boxes and not of v , the swelling determined in the tall boxes. This result is true whichever v parameter is used.

Not all the v parameters are equally effective in measuring the two characteristic properties mentioned above. Table XXIII showed that v_4 had the highest correlation with B , while v_5 and v_6 had the lowest. Table XXV shows, however, that if X or M is being predicted from B , v_5 and v_6 add the most to the regression equation and v_4 and v_3 add least.

Table XXV. *Increased proportion of the total variance of M or X accounted for by adding different v parameters to the independent variate.*

Tall boxes						
	$1 - R^2_{X.B}$	$1 - R^2_{X.Bv}$	$\Delta(v)$			
v_1	0.3451	0.3137	0.0314			
v_3	—	0.3410	0.0041			
v_4	—	—	—			
v_5	—	0.3053	0.0398			
v_6	—	0.3083	0.0368			
Short boxes						
	$1 - R^2_{X.B}$	$1 - R^2_{X.Bv'}$	$\Delta(v')$	$1 - R^2_{M.B}$	$1 - R^2_{M.Bv'}$	$\Delta(v')$
v_1	0.3451	0.2605	0.0867	0.1690	0.1504	0.0186
v_3	—	0.3129	0.0322	—	0.1632	0.0058
v_4	—	0.2789	0.0662	—	0.1569	0.0121
v_5	—	0.2418	0.1033	—	0.1466	0.0224
v_6	—	0.2354	0.1097	—	0.1400	0.0290

It is interesting to compare this table with Table XIX, the corresponding one for the p parameters. But the discussion of this comparison will be reserved for the next section.

286 *Significance of Certain "Single Value" Soil Constants*

So far then it has been shown

(1) that the swelling parameters are complex, and do not measure any single property accurately,

(2) they are correlated most closely with the base exchange capacity,

(3) they seem to depend on the structure of the soil, but the better they measure the base exchange capacity, the less information do they give about the structure.

In concluding the remarks on the interpretation of the soil constants derived from the box, it has been shown that

(1) the weight of water per unit weight of oven-dry soil in the box seems to be a remarkably good measure of the base exchange capacity of the soil,

(2) the pore space and the swelling parameters are affected by two distinct factors, one being the base exchange capacity and the other probably being the soil structure.

p_2 and v_s are probably the two most valuable of the box constants investigated, though p_3 , which is not a box constant, is probably even more valuable than p_2 .

THE INTERPRETATION OF THE MOISTURE EQUIVALENT AND XYLENE EQUIVALENT OF SOILS.

The moisture equivalent, M , and the xylene equivalent, X , of a soil are defined as the weight of water or xylene held by 100 gm. of oven-dry soil in a centrifugal field of 1000 g determined under certain standardised conditions. The soil is placed in perforated boxes arranged around the periphery of the centrifuge drum, so that when the drum rotates the liquid is thrown out through the perforations. The standard conditions of running include a standard time, since appreciable evaporation takes place from the outside of the rotating drum, and a standard height of soil in the box, for the moisture held per gram of soil decreases as the height of the soil in the box increases. Fundamentally the moisture equivalent and the box experiments are closely related, the only difference between them being that w , the water held by the soil, is measured in a gravitational field of g , while M is measured in a field of 1000 g . Thus both M and w decrease with increasing height of the soil in the box, and both are increased a little by wetting the soil under vacuum.

The moisture equivalent was originally intended to measure the weight of water adsorbed by the soil colloids together with the weight held in the fine soil capillaries. It was assumed that at 1000 g practi-

cally all the water in the coarse capillaries or soil macropores would be thrown out, but that little of the water in the fine capillaries or micropores would be. There is, however, no sharp division between macropore and micropore water as determined in the centrifuge, for Lebedeff(11) showed that the moisture equivalent decreases continuously as the centrifugal field increases up to about 18,000 *g*, after which it remains sensibly constant up to 70,000 *g*. The small decrease he observed after 18,000 *g* he put down to increased evaporation due to the high speed of rotation. The xylene equivalent was assumed to measure the soil micropore space, for it was also assumed that no xylene was adsorbed by the soil colloids. These ideas will not be discussed in greater detail until the theory of imbibitional water is considered in the next section, but it is quite evident that neither the moisture equivalent nor the xylene equivalent are measuring any simple fundamental property of the soil.

Both the moisture equivalent and the xylene equivalent are determined very largely by the mechanical composition of the soil. Table XXVI shows the percentage of the total variance of a parameter λ accounted for by *C*, the clay content, and by *C* and *F*, the clay content plus the fine-silt content.

Table XXVI. *The influence of clay and silt on soil parameters.*

Percentage variance accounted for by	For untreated soils								
	<i>S</i>	<i>h</i>	<i>I</i>	<i>p'</i>	<i>w'</i>	<i>v'</i>	<i>M</i>	<i>X</i>	<i>B</i>
Clay	54.42	59.79	56.52	59.58	52.33	29.52	69.17	72.58	51.54
Fine silt	4.56	10.54	5.57	6.93	8.04	0.35	13.04	12.55	7.12
Clay and fine silt	58.98	70.32	62.09	66.51	60.37	29.88	82.21	85.13	58.66
	For peroxide-treated soils								
	<i>S_p</i>	<i>h_p</i>	<i>I_p</i>	<i>p_p'</i>	<i>w_p'</i>	<i>v_s'</i>			
Clay	65.70	63.05	67.85	71.60	65.48	25.25			
Fine silt	7.14	9.02	3.58	12.19	12.97	4.74			
Clay and fine silt	72.84	72.07	71.43	83.79	78.45	29.99			

C and *F* together account for 85 per cent. of the total variance of *X*, and 82 per cent. of the total variance of *M*, which is much larger than for any other variate determined on the untreated soil. Table XXVII, however, shows that the residual variance of *M* and *X* cannot be further decreased by taking account of the coarse silt, nor by splitting the fine silt up into its two fractions.

288 *Significance of Certain "Single Value" Soil Constants*

Table XXVII. *Influence of the silt fractions on some soil parameters (59 soils only used).*

	$\lambda =$	B	h	I	M	X
Variance accounted for by C	50.71	58.51	54.61	67.86	71.13	
Additional variance accounted for by						
Fine silt I = F_1	8.32	11.06	3.47	10.41	8.60	
Fine silt II = F_2	1.04	1.76	2.29	3.84	4.52	
Coarse silt = G	0.10	—	—	0.58	0.10	
F_1 and F_2 together	9.36	12.82	5.76	14.94	13.13	
$F = F_1 + F_2$	8.02	11.32	5.75	13.78	12.99	

The xylene equivalent.

The xylene equivalent has two important fundamental properties, the first, as already shown, being that it is largely controlled by the amount of silt and clay present, and the second that it is independent of the amount of organic matter present. To establish this second property, Table XXVIII shows that the xylene equivalent of the untreated soil is much closer related to properties of the peroxide-treated soil than to properties of the untreated soil.

Table XXVIII. *Correlation coefficients of X with other soil parameters.*

Parameter measured on	S	h	I	p_1'	w'	v_1'	B	C
Untreated soil	0.8245	0.8606	0.8543	0.8477	0.8416	0.4999	0.8092	0.8519
Peroxidised soil	0.9234	0.8942	0.9141	0.9426	0.9351	0.4407	—	—

Table XXIX shows that all the relevant information about X , supplied by a parameter λ determined on the untreated soil, is contained in the corresponding parameter λ_p determined on the peroxide-treated soil, the parameter v_1' being the only exception.

Table XXIX. *Influence of peroxide-treated soil parameters on the X correlations.*

λ	$1 - R^2_{X, \lambda_p}$	$1 - R^2_{X, \lambda_p \lambda}$	$\Delta (\lambda)$
S	0.1473	0.1467	0.0006
h	0.2075	0.2049	0.0026
I	0.1644	0.1643	0.0001
p_1'	0.1116	0.1107	0.0009
w'	0.1255	0.1254	0.0001
v_1'	0.8058	0.7076	0.0982

Thus the xylene equivalent is independent of the amount of organic matter affected by treatment with hydrogen peroxide in the soil, but is measuring a property of the mineral fraction.

From Table XXVIII it is evident that X is largely determined by p_p' . v_p' , S_p or C when added to the p_p' regression increase the accuracy of the X prediction as is shown in Table XXX.

Table XXX. *Influence of other variates on the regression of X on p_p' .*

λ	$1 - R^2_{X.p_p'}$	$1 - R^2_{X.p_p'\lambda}$	$\Delta(\lambda)$
S_p	0.1116	0.1014	0.0102
h_p	—	0.1097	0.0019
I_p	—	0.1055	0.0061
w_p'	—	0.1056	0.0060
v_p'	—	0.0905	0.0211
C	—	0.1025	0.0091

The additions due to w_p' and I_p are due entirely to their correlation with S_p , for

$$1 - R^2_{X.S_p v_p'} = 0.1014,$$

$$1 - R^2_{X.S_p p_p' I_p w_p'} = 0.1003,$$

so that

$$\Delta(I_p w_p') = 0.0011,$$

which is not significant. C and F , however, add information not contained in S_p , for, as is shown in Table XXXI, given p_p' , S_p and CF appear to be uncorrelated variates, and to add to the X regression independently of each other, that is, they supply different types of information.

Table XXXI. *Influence of clay and silt on the X regression.*

$1 - R^2_{X.p_p'\lambda\lambda'}$	$\lambda' = 0$	$\lambda' = CF$	$\Delta(CF)$
$\lambda = 0$	0.1116	0.0928	0.0188
$\lambda = S_p$	0.1014	0.0832	0.0181
$\Delta(S_p)$	0.0102	0.0095	0.0007

The swelling parameters v' and v_p' also add considerably to the regression, as is shown in Table XXXII. Given the S_p and p_p' terms in the prediction of X , CF and $v'v_p'$ act as independent pairs of variates, but given the p_p' term, S_p and $v'v_p'$ each give more information when used together than when used separately.

Table XXXII. *Influence of the swelling parameters on the X regression.*

$1 - R^2_{X.S_p p_p' \lambda \lambda'}$				$1 - R^2_{X.p_p' CF \lambda \lambda'}$		
λ	$\lambda' = 0$	CF	$\Delta(CF)$	0	S_p	$\Delta(S_p)$
0	0.1014	0.0832	0.0181	0.0928	0.8032	0.0095
$v'v_p'$	0.0592	0.0443	0.0149	0.0689	0.0443	0.0245
$\Delta(v'v_p')$	0.0422	0.0389	0.0032	0.0239	0.0389	-0.0150

290 Significance of Certain "Single Value" Soil Constants

But the high correlation of p_p' with X , on which all this analysis is based, may be largely due to the high correlations of both X and p_p' with C and F . The next table shows that w_p' is a more satisfactory variate than p_p' in the multiple regression equation for X at any stage until the last, when they are both equal.

Table XXXIII. Influence of variates on the $X.CF$ regression.

λ	$1 - R^2_{X, \lambda CF}$	$1 - R^2_{X, \lambda_p CF}$	$1 - R^2_{X, \lambda_p v' v_p' CF}$	$1 - R^2_{X, \lambda_p v' v_p' S_p CF}$
S	0.1134	0.0911	—	—
h	0.1233	0.1178	—	—
I	0.1040	0.0897	0.0666	—
p'	0.1172	0.0928	0.0689	0.0443
w'	0.1094	0.0879	0.0532	0.0459

$$1 - R^2_{X, CF} = 0.1487.$$

The other properties of the multiple regression equation containing w_p' instead of p_p' remain the same, as is seen in Table XXXIV, which shows that both CF and $v'v_p'$ and CF and S_p act as independent variates, but that S_p and $v'v_p'$ show an interaction, though not so marked as with p_p' .

Table XXXIV. Analysis of the contributions made by certain variates to the $X.w'$ regression.

$1 - R^2_{X, S_p w_p' \lambda \lambda'}$				$1 - R^2_{X, w_p' CF \lambda \lambda'}$		
λ	$\lambda' = 0$	CF	$\Delta(CF)$	0	S_p	$\Delta(S_p)$
0	0.1219	0.0855	0.0364	0.0879	0.0855	0.0024
w_p'	0.0768	0.0459	0.0309	0.0532	0.0459	0.0073
$\Delta(w_p')$	0.0451	0.0396	0.0055	0.0347	0.0396	-0.0049

$$1 - R^2_{X, w_p' \lambda \lambda'}$$

λ	$\lambda' = 0$	CF	$\Delta(CF)$
0	0.1255	0.0879	0.0376
S_p	0.1219	0.0855	0.0364
$\Delta(S_p)$	0.0036	0.0024	0.0012

A further analysis of these results was undertaken to find the influence of other p and v parameters on the X regression. Simple substitution of these parameters in the full X regression makes very little difference to the total variance of X unaccounted for, but, as will be shown later, this is probably because the residual variance of X from the regression equation is mainly controlled by the experimental errors of the independent variates.

Table XXXV. *Residual variance of X when using different p and v parameters.*

λ	$\lambda' =$	$1 - R^2_{X, CF\lambda\lambda'}$		
		$v'v_{p'}$	$v'_s v'_{sp}$	$v'_s v'_{sp}$
$p_{p'}$		0.0689	0.0692	0.0670
$s_p p_{p'}$		0.0443	0.0453	0.0437
$s_p p'_{sp}$		—	—	0.0471

These variates, however, alter the relative importance of some of the terms in the regression, as is shown in Table XXXVI.

Table XXXVI. *Analysis of the contributions of p'_{1p} and p'_{2p} to the X regression.*

λ	$\lambda' =$	$1 - R^2_{X, S_{p\lambda}\lambda'}$		
		0	v'_{sp}	$\Delta(v'_{sp})$
p'_{1p}		0.1014	0.0622	0.0392
p'_{2p}		0.0761	0.0703	0.0058
$\Delta(p'_{1p} - p'_{2p})$		0.0253	-0.0081	0.0334

The interpretation of these equations is, unfortunately, very difficult. The xylene equivalent is not simply proportional to the base exchange capacity of the mineral portion of the soil together with some simple term to take account of the structure of the sieved air-dry soil used in the experiment, for under these conditions it should be determined by w_p' —which is presumably proportional to the base exchange capacity of the peroxide-treated soil and therefore of the mineral portion of the untreated soil—and by some combination of the structure parameters of the untreated soil, such as the p 's and v 's. Turning to the data, w_p' is found to be a very important parameter in the prediction of the xylene equivalent, but the structure parameters of the untreated soil are not, as is shown in Table XXXVII.

Table XXXVII. *Influence of the structure parameters of the untreated soil on the $X.w_p'$ regression.*

	$1 - R^2_{X, w_p' p'}$	$\Delta(p')$		$1 - R^2_{X, w_p' v'}$	$\Delta(v')$
p'_1	0.1245	0.0011	v'_1	0.1115	0.0141
p'_2	0.1132	0.0124	v'_5	0.1139	0.0117
p'_3	0.1149	0.0107	v'_6	0.1127	0.0129

$1 - R^2_{X, w_p'} = 0.1256.$

Table XXXVIII, however, shows that the structure parameters of the peroxide-treated soil are important.

Table XXXVIII. *Influence of the structure parameters of the peroxide-treated soil on the $X.w_p'$ regression.*

	$1 - R^2_{X.w_p'p_p'}$	$\Delta(p_p')$		$1 - R^2_{X.w_p'v_p'}$	$\Delta(v_p')$
p'_{1p}	0.1056	0.0200	v'_{1p}	0.0934	0.0322
p'_{2p}	0.0858	0.0398	v'_{2p}	0.0906	0.0350
			v'_{3p}	0.0930	0.0326

$$1 - R^2_{X.w_p'} = 0.1256.$$

The preliminary analysis showed that the sticky point of the peroxide-treated soil appeared to be useful for predicting the xylene equivalent. Table XXXIX shows that the prediction can be markedly improved if a structural parameter of the peroxide-treated soil is added to this.

Table XXXIX. *Influence of structure parameters of the peroxide-treated soil on the $X.S_p$ regression.*

	$\lambda =$	0	v'_{3p}	$\Delta(v'_{3p})$	p'_{2p}	$\Delta(p'_{2p})$	$v'_{3p}p'_{2p}$	$\Delta(v'_{3p}p'_{2p})$	$\Delta(v'_{3p}p'_{2p}) - \Delta(p'_{2p})$
$1 - R^2_{X.S_p\lambda}$	0.1473	0.1006	0.0467	0.0761	0.0712	0.0703	0.0689	0.0530	0.0058
$1 - R^2_{X.S_pw_p'\lambda}$	0.1219	0.0806	0.0413	0.0760	0.0459	0.0689	0.0530	0.0071	—
$\Delta(w_p')$	0.0254	0.0200	—	0.0001	—	0.0014	—	—	—

The main result from Table XXXIX is that w_p' , a parameter presumably closely correlated with the base exchange capacity of the mineral portion of the soil, has no influence on the $X.S_p p'_{2p}$ regression. If, instead of using the hypothesis that the xylene equivalent is measuring the base exchange capacity of the mineral portion of the soil, one used the hypothesis that it is measuring the sticky point of the mineral portion of the soil, but is affected by the structure of the soil, p'_{2p} would appear to be the most useful single structure parameter to use. It is not, however, a structure parameter of the soil used in the experiments to determine the xylene equivalent, but of the soil after it has been boiled with hydrogen peroxide, air-dried, and ground to pass through the sieves. This hypothesis thus has two consequences, the first being that these structure parameters are measuring inherent properties of the soil and not mere accidental properties of the structure the soil happened to possess at the time of the experiment, and the second being the surprising one that xylene can ignore the effects of the organic matter so completely that it can to some extent measure a structure property which the soil would possess if the organic matter were removed. Alternatively, the second consequence is that there was not a sufficient quantity of organic matter present to swamp the structure of the mineral portion of the soil.

The xylene equivalent is not completely determined by S_p , p'_{2p} and v'_{6p} , for the amount of clay and silt, and to a very minor extent v'_6 still adds to the regression, as is shown in Table XL.

Table XL. *Contribution of clay and silt and of v'_6 to the X regression.*

λ'	$\lambda =$	$1 - R^2_{X.S_p p'_{2p} v'_{6p} \lambda \lambda'}$			$1 - R^2_{X.S_p p'_{1p} v'_{6p} \lambda \lambda'}$		
		0	CF	$\Delta(CF)$	0	CF	$\Delta(CF)$
0		0.0703	0.0493	0.0210	0.0622	0.0470	0.0152
v'_6		0.0657	0.0471	0.0186	0.0560	0.0437	0.0123
$\Delta(v'_6)$		0.0046	0.0022	—	0.0062	0.0033	—

The clay and the silt contribute about equally to the above regression, for

$$\begin{aligned}
 1 - R^2_{X.v'_{6p} p'_{2p} S_p} &= 0.0703, \\
 1 - R^2_{X.v'_{6p} p'_{2p} S_p C} &= 0.0596, \text{ giving } \Delta(C) = 0.0107, \\
 1 - R^2_{X.v'_{6p} p'_{2p} S_p CF} &= 0.0493, \text{ giving } \Delta(F) = 0.0103, \\
 1 - R^2_{X.v'_{6p} p'_{1p} S_p} &= 0.0622, \\
 1 - R^2_{X.v'_{6p} p'_{1p} S_p C} &= 0.0545, \text{ giving } \Delta(C) = 0.0077, \\
 1 - R^2_{X.v'_{6p} p'_{1p} S_p CF} &= 0.0470, \text{ giving } \Delta(F) = 0.0075.
 \end{aligned}$$

It is not possible to decide from the data exactly what proportion of the residual variance of X can be ascribed to experimental error, since no estimates of the errors in C and F are available. The residual variance of X from the regressional equation containing S_p , p'_2 , v'_6 , v'_{6p} , C and F is 0.997 per degree of freedom, based on 57 degrees of freedom, while the errors between duplicates in the determinations of S_p , v'_6 , v'_{6p} , p'_2 and X will only account for a residual variance of 0.137 per degree of freedom. The difference is thus larger than can be accounted for by experimental error but, since all the estimates of error are lower estimates, owing to the neglect of systematic errors, it is fair to conclude that the xylene equivalent of the oven-dry untreated soils can be calculated almost within the limits of experimental error from parameters which are determined on the peroxide-treated soils. These parameters are the sticky point, a pore-space measurement, a swelling measurement, and the amount of clay and silt in the soil. By choosing the pore-space measurement used, the relative importance of the swelling term can be altered very considerably. Supposing these last two terms are really structure parameters of the soil, the conclusion reached is that p_2 , the estimate of the air-pore space made in the box, is more useful than p_1 , the estimate of the water-pore space made in the box, and contains practically all the information supplied by the swelling parameters, but

294 Significance of Certain "Single Value" Soil Constants

that p_1 and a suitable swelling parameter, such as v_s or v_a , the ratios of the weight of water in the swollen soil to the weight of water in the residual soil or to the weight of water in the whole box, contains more information than p_2 .

The moisture equivalent.

Turning to the moisture equivalent data, Table XLI gives the correlation coefficients of the moisture equivalent of the air-dry soil with some of the other variates under consideration.

Table XLI.

Variate obtained using	S	h	I	p'	w'	v'	B	X
Untreated soil	0.9112	0.9280	0.9240	0.8998	0.9222	0.6720	0.9116	0.9555
Peroxide-treated soil	0.9289	—	0.9411	0.9543	0.9543	0.4918	—	—

The variates I_p , p_p' and w_p' obtained from the peroxide-treated soil appear to be correlated closer with M than with the corresponding variates obtained from the untreated soil, though these latter parameters can no longer be ignored as they could be in the X regression.

Table XLII. *Influence of peroxide-treated soil parameters on the M regression.*

λ	$1 - R^2_{M.\lambda p}$	$1 - R^2_{M.\lambda \lambda p}$	$\Delta(\lambda)$
S	0.1371	0.0981	0.0390
I	0.1143	0.0968	0.0175
p'	0.0893	0.0843	0.0050
w'	0.0893	0.0660	0.0233

Both I and w' add to the regression, but, as will be seen later, this addition is due to the influence of B , the base exchange capacity. Table XLI showed that p_p' , w_p' and X are all equally strongly correlated with M , but the high correlations of p_p' and w_p' with M are only a reflection of their high correlations with X . If M is being predicted from X , adding B to the regression improves the prediction remarkably, and this is still further improved, though only slightly, by a structure parameter.

Table XLIII. *Value of $1 - R^2_{M.X\lambda}$ for different variates.*

Parameter obtained on	S	h	I	p'	w'	v'	C	B
Untreated soil	0.0394	0.0440	0.0441	0.0584	0.0396	0.0367	0.0859	0.0316
Peroxide-treated soil	0.0723	—	0.0592	0.0612	0.0576	0.0808	—	—

$$1 - R^2_{X.M} = 0.0870.$$

Table XLIV. *Influence of the structure parameters on the $M.XB$ regression.*

Parameter λ	$1 - R^2_{M.XB\lambda}$		Parameter λ	$1 - R^2_{M.XB\lambda}$
	Tall boxes	Short boxes		
v_1	0.0271	0.0286	p'_1	0.0312
v_4	—	0.0282	p'_2	0.0293
v_5	0.0279	0.0275	p'_3	0.0315
v_6	0.0282	0.0294		

$$1 - R^2_{M.XB} = 0.0316.$$

Thus some of the swelling parameters definitely increase the accuracy of the prediction formula, but they do not account for the whole of the residual variance of M , for, using the $M.XBv_1$ regression, the residual variance of M unaccounted for by these three variates is 2.233 per degree of freedom, while the estimate of the variance of M due to experimental error is 0.448 per degree of freedom.

The influence of other variates besides the structural parameters on the regression of M on X and B is small, owing to the high correlation of these variates with B . Thus

$$1 - R^2_{M.XB} = 0.0316, \quad 1 - R^2_{M.XBS} = 0.0298, \quad \Delta(S) = 0.0018,$$

$$1 - R^2_{M.XBw'} = 0.0315, \quad \Delta(w') = 0.0001.$$

Further, X is a better variate to take with B for predicting M than p'_1 or w'_1

$$1 - R^2_{M.XB} = 0.0316,$$

$$1 - R^2_{M.p'_1B} = 0.0564, \quad \Delta(p'_1 - X) = 0.0248,$$

$$1 - R^2_{M.w'_1B} = 0.0667, \quad \Delta(w'_1 - X) = 0.0351.$$

for although by themselves p'_1 and w'_1 are as strongly correlated with M as is X , yet in conjunction with B , X is seen to give a considerably better prediction.

Besides these determinations of the moisture equivalent made on the air-dry soils, a parallel set was made on the oven-dry soils, and these were done simultaneously with the xylene equivalent determinations, for which oven-dry soils were also used. The moisture equivalent of an oven-dried soil is lower than that of the air-dry soil. Using the mean value for the 64 Natal soils

$$\bar{M} \text{ (air-dry soil)} = 24.56 \%, \quad \Sigma(M - \bar{M})^2 = 4944.03,$$

$$\bar{M}' \text{ (oven-dry soil)} = 22.52 \%, \quad \Sigma(M' - \bar{M}')^2 = 4017.37,$$

296 *Significance of Certain "Single Value" Soil Constants*

so that not only is the mean value of M reduced, but also its variability by oven-drying. Further, the correlation with other variates is higher using M than M' .

Table XLV. *Comparison of M and M' as prediction parameters.*

$\lambda =$	X	I	B	v_1	I_p
$r_{M\lambda}$	0.9555	0.9280	0.9116	0.7703	0.9411
$r_{M'\lambda}$	0.9579	0.9088	0.9000	0.7663	0.9388
$(1 - r^2_{M'\lambda}) - (1 - r^2_{M\lambda})$	-0.0046	0.0351	0.0210	0.0062	0.0041
$1 - R^2_{B, M'X} = 0.1251$		$1 - R^2_{B, M'X} = 0.1560$		$\Delta (M - M') = 0.0309$	
$1 - R^2_{M, XBv'} = 0.0877$		$1 - R^2_{B, M'Xv'} = 0.1025$		$\Delta (M - M') = 0.0148$	

That M' should predict X a little better than M is not surprising, since M' and X were both determined simultaneously on oven-dry soil, while M was determined independently on air-dry soil. A preliminary examination of the factors influencing the effect of oven drying on M was undertaken. Let $\underline{M} = M - M'$, that is \underline{M} represents the reduction in the moisture equivalent of a soil due to its being oven dried. The next table gives the more important correlation coefficients.

Table XLVI. *Correlation coefficients of \underline{M} with certain other variates.*

$\lambda =$	M	X	B	I	v_1
$r_{M\lambda}$	0.6866	0.5986	0.6527	0.6820	0.5179

There is some slender evidence that it is the organic matter that is affected by oven drying, for the regression of \underline{M} on I is large, and is not significantly increased if B is added:

$$1 - R^2_{\underline{M}, I} = 0.5349,$$

$$1 - R^2_{\underline{M}, IB} = 0.5319, \quad \Delta(B) = 0.0030.$$

The result reached in this investigation on the interpretation of the moisture equivalent is that it is almost completely determined by the xylene equivalent, X , and the base exchange capacity, B , of the soil. No additional variates appreciably increase the accuracy of the prediction, though some of the structure parameters, *e.g.* v , do add something. Organic matter seems to influence the moisture equivalent only through its base exchange capacity. Oven drying the soil before determining its moisture equivalent has only a minor effect on the above properties. But the fundamental question whether the moisture equivalent and the xylene equivalent are measuring two radically different

properties of the soil, or whether they are measuring two closely related properties, cannot be answered from this data, for there are not criteria available to decide whether the properties they are measuring are really radically different but happen to be closely correlated over the geographical region sampled.

THE IMBIBITIONAL WATER THEORY.

The original reason why the xylene equivalent measurements were made on this series of soils was to allow of an examination of the imbibitional water held by soils. The imbibitional water theory assumes that this water can be divided into two parts:

- (a) water colloiddally bound or imbibed by the soil colloids;
- (b) water held by surface tension forces in the fine soil pores and capillaries.

The fundamental weakness of the theory is that there exists no method of making this division. If Patrick's⁽¹³⁾ capillary condensation theory is relevant for soils, it would imply that all the water held by a soil is in fine capillaries, for water so held has a lower free energy and therefore a higher density and higher boiling-point than water in a wide capillary. Thus, on this theory, none of the water held by the soil would be bound to the surfaces of the colloidal particles. This theory, however, cannot account for all the water held by a soil, for it offers no explanation of the rigidity properties of soil pastes and suspensions. To enable this division into imbibed and micropore water to be made, unproved, and probably only partially true, hypotheses must be used.

If (a) all the micropores are sufficiently large so that when filled with water the volume of the system remains unchanged; (b) when water is colloiddally bound, the volume of the system increases by the volume occupied by the bound water, then this latter volume would be equal to the volume expansion of the soil on wetting, and so would be measurable. As already stated, swelling measurements made in the Keen-Raczkowski boxes do not measure this quantity accurately, as other factors affect the swelling considerably. The Haines⁽⁷⁾ constant volume bottle possibly provides a more suitable method.

Fisher⁽⁵⁾ proposed a method of estimating the weight of imbibitional water held by a soil by assuming that the volume of xylene held by a soil under specified conditions equalled the volume of water held in the fine pores under comparable conditions. But this assumption suffers from three defects:

298 *Significance of Certain "Single Value" Soil Constants*

(1) It assumes all the micropores are large, in the sense that the density of water in the pores is unity.

(2) When a dry soil is wetted with water it swells much more than if it is wetted with xylene, so that the detailed geometry of the pore space in a soil wet with water is different from that wet with xylene.

(3) The interfacial tension between the soil, the xylene and the air is different from that of the soil-water-air interfacial tension, so that under a given centrifugal force the types of pores filled with the two liquids will not be identical.

The last two factors counterbalance each other to some extent, for when the soil swells the imbibed water fills up some of the fine pores, and since xylene has a lower interfacial tension than the water, it only fills a fraction of the pore space the water would have filled if it had not been imbibed.

There appear to be no *a priori* methods available to test the validity of the imbibitional water theory, but it is possible to obtain *a posteriori* evidence of its plausibility. Suppose that the amount of water colloiddally bound to the soil is more closely correlated with the base exchange capacity and other colloidal parameters than the moisture equivalent is. This supposition is limited to cases in which the proportion of the different exchangeable ions remains substantially constant. In these soils determinations of the relative amounts of exchangeable ions have been made, though some certainly contain much more exchangeable magnesium than others, and it is unlikely any are very acid, but there is probably a fairly wide range in the relative proportions of the hydrogen, calcium and magnesium ions present. Let J be the imbibitional water held by the soil, expressed in grams of water per 100 gm. of dry soil, then by definition

$$J = M - \frac{X}{\rho},$$

where ρ is the density of the xylene used. It should be noted that Fisher expressed the imbibitional water as grams of water per 100 c.c. of dry soil, so that the figures used here would have to be multiplied by the soil density to bring them into line with his. The following table gives some comparisons of the corresponding correlation coefficients when J and M are used as independent variates.

J predicts B better than M does, though M and X used as independent variates give a still better prediction, but otherwise M gives higher correlations than J with the other colloidal parameters, which can again be improved by using X as an independent variate. There

are three possible reasons why M might predict these other parameters better than J , namely:

(1) The other parameters are not purely colloidal, but depend on the micropore structure of the soil.

(2) M may take account of the different proportions of the exchangeable ions in the soil better than J .

(3) J may have been computed wrongly, due to the partial failure of some of the conditions on which the calculation is based.

Table XLVII. *Comparison of the M , MX and J correlation coefficients.*

$\lambda =$	B	h	S	w'
$r_{J\lambda}$	0.9224	0.8912	0.9019	0.9034
$r_{M\lambda}$	0.9116	0.9279	0.9112	0.9222
$1 - R^2_{\lambda..J}$	0.1492	0.2058	0.1866	0.1839
$1 - R^2_{\lambda..M}$	0.1690	0.1389	0.1697	0.1496
$1 - R^2_{\lambda..MX}$	0.1251	0.1310	0.1451	0.1316

With regard to possibility (1), h , the water held by a soil in a 50 per cent. relative humidity atmosphere, is usually considered a pure colloidal parameter, while S and w' are not. It is very difficult to decide if all the water so adsorbed by a soil really is colloiddally bound, but some evidence might be afforded from the fact that

$$1 - R^2_{h..B} = 0.0817,$$

while

$$1 - R^2_{h..Bv'} = 0.0672,$$

and

$$1 - R^2_{h..BM} = 0.0642.$$

Obviously h is mainly a colloidal property, but since it is affected by v' and M as well as by B this would imply either that h does to some extent depend on the soil structure as measured by M or v' (though not by p'), or that it is affected by the proportion of the different exchangeable ions in the soil, and this effect is to some extent allowed for by M or v' . But the third possibility must certainly be considered. Table XLVII showed that treating M and X as independent variates, they predict B better than they do any other variate, and this has been found true for all the variates examined, not only for the four given in the table. If the regression equation for a variate λ is written as

$$\lambda = \alpha + \beta \left(M - \frac{X}{\rho_e} \right),$$

300 *Significance of Certain "Single Value" Soil Constants*

where ρ_c is the hypothetical density of the xylene necessary to make the imbibitional water equation the regression equation, the values of ρ_c with their standard errors are found to be:

λ	B	h	S	w'	ρ (xylene) = 0.856
ρ_c	1.149	2.084	1.372	1.576	
$s(\rho_c)$	0.146	0.287	0.279	0.126	

The values of ρ_c come out too high, though for B and S they are only twice their standard error greater than ρ , the true density of the xylene. With the exception of the value for h , the three values of ρ_c seem to agree fairly well amongst themselves, and lend support to the hypothesis that the imbibitional water really is given by

$$J = M - \frac{X}{\rho_c}.$$

There are two obvious explanations why ρ_c should be larger than ρ , namely that the xylene-pore space is larger than the water-pore space, due to the imbibed water filling all the finer capillaries, and that some xylene is imbibed by the soil. Considering the first explanation by itself, the moisture equivalent can be written as

M = volume of imbibitional water + volume of water in the micropores.

If a fraction δ of the micropores that hold xylene are filled with imbibitional water, then

$$M = J + \frac{X}{\rho}(1 - \delta).$$

But from the definition of ρ_c

$$J = M - \frac{X}{\rho_c},$$

so that

$$\frac{1}{\rho_c} = \frac{1}{\rho}(1 - \delta) \quad \text{or} \quad \delta = \frac{\rho_c - \rho}{\rho_c}.$$

Using $\rho_c = 1.149$ and $\rho = 0.856$, this gives $\delta = 0.255$, or 25 per cent. of the micropores as determined by the xylene equivalent are closed by the swelling of the soil colloids on imbibing water; a result that is not *a priori* impossible. On the other hand, if the whole difference was due to xylene being imbibed by the soil, δ would be the proportion of the total xylene held that was adsorbed, and since a 25 per cent. adsorption is very improbable, the second possibility, by itself, is not sufficient. The possibility that the density of the imbibed water is greater than unity does not affect the result, for the volume of this water is not

measured, though the volume of the water in the micropores is assumed equal to the weight of water there.

To summarise this section, while no direct proof has been obtained about the existence of imbibitional water, it is not impossible that it can be calculated from the moisture and xylene equivalents, although the failure of certain assumptions invalidates the simple calculation that weight of imbibitional water per gram of soil

$$= \text{moisture equivalent} - \frac{\text{xylene equivalent}}{\text{density of xylene}}.$$

But from the practical point of view no new information is given by this quantity since it is calculated *a posteriori* from the data, and since the same data can give better predictions of the soil parameters when unhampered by the assumptions of this theory.

THE RELATION BETWEEN BASE EXCHANGE CAPACITY AND OTHER SOIL VARIATES.

The primary colloidal properties of a soil are largely controlled by three factors:

- (1) The amount of colloidal materials present in the soil.
- (2) The types of colloidal material present, as measured for example by their titration curves.
- (3) The composition of the exchangeable ions adsorbed by the colloidal material.

The purpose of this section is to examine how far these various factors affect the soil variates already dealt with, so that some idea can be formed of what type of information about the colloid status of the soil is given by any one of them. Probably none of the above factors has been directly measured, though the product of the first two has, for the base exchange capacity of the soils has been determined, where the base exchange capacity has been defined as the amount of exchangeable hydrogen, calcium and magnesium the soil will give up to a potassium phosphate buffer at pH 6.5. The amount of colloidal material in the soil may have been measured if it is assumed equal to the clay content. The term colloidal material lacks precise definition. If it is defined as all material whose particles are less than a given size, and if the upper limit chosen happens also to be the upper limit of the clay particles, the amount of clay and of colloidal material are by definition equal. But if some other limit or definition of colloidal material is taken, as for example, that its base exchange capacity or its heat of wetting per gram

302 *Significance of Certain "Single Value" Soil Constants*

must exceed an arbitrary minimum, then it may happen that some of the fine silt must be classed as colloidal or that some of the clay fractions must be classed as non-colloidal, in which case the amount of clay would not necessarily be proportional to the amount of colloidal material present. Certainly for the Natal soils the base exchange capacity of the soil is not proportional to the amount of clay present, which means either that the base exchange capacity of the colloidal material present is not constant, or that the amount of clay present only gives a poor measure of this quantity. This point is seen from the following correlation table.

Table XLVIII. *Correlation coefficients of B with certain other soil variates.*

Parameter determined on	<i>S</i>	<i>h</i>	<i>I</i>	<i>w'</i>	<i>p'</i>	<i>v'</i>	<i>M</i>	<i>X</i>	<i>C</i>
Untreated soil	0.9416	0.9583	0.9271	0.9699	0.9267	0.8223	0.9116	0.8092	0.7179
Peroxide-treated	—	—	0.9026	0.8806	0.8575	0.4927	—	—	—

The important point to notice from this table is that the base exchange capacity of the soil itself is much more closely related to most of the other variates than it is to the clay content. Even if the proportion of silt is added to the regression the correlation is only slightly improved for $\bar{R}_{B.CF} = 0.7570$. Thus if the quantity of colloidal material present in the soil is proportional to the clay content, this result means that such quantities as *S*, *h*, *w'* are mainly controlled by the quantity of exchangeable ions present in the soil, and much less by the type of colloidal material present. The following table bears this out by showing that if a variate is being predicted from the base exchange capacity, adding the clay content to the regression barely affects its residual variance.

Table XLIX. *Influence of the clay content on some B regressions.*

$\lambda =$	<i>h</i>	<i>w'</i>	<i>S</i>	<i>I</i>
$1 - R^2_{\lambda.B}$	0.0817	0.0592	0.1133	0.1405
$1 - R^2_{\lambda.BC}$	0.0667	0.0577	0.1055	0.1251
$\Delta(C)$	0.0150	0.0015	0.0078	0.0153

Another point to notice from Table XLVIII is that *B* is more closely correlated with *w'* than it is with *h*. This result is rather surprising, for *B* and *h* are usually regarded as properties of the soil colloids only, while *w'* is certainly not. This anomaly is presumably connected with the following two facts:

(1) The method employed to determine the base exchange capacity under-estimates the replaceable calcium and magnesium in neutral soils, and over-estimates the exchangeable hydrogen in very acid soils.

(2) A Ca- or Mg-saturated soil is known to hold more water in a 50 per cent. relative humidity atmosphere than the corresponding H-saturated soil, but the H-saturated soil holds more water at saturation than the Ca- or Mg- soil.

When the relation between B and w' is being considered, the over-estimation of the amount of exchangeable hydrogen and the under-estimation of exchangeable calcium compensate for the greater wetness of the hydrogen over the calcium soil. But when the relation between B and h is being considered, these two effects work in opposite directions, for the Ca- soil, in which the calcium is under-estimated, is wetter than the H- soil, in which the hydrogen is over-estimated.

Since the determination of B is subject to errors depending on the proportions of exchangeable hydrogen and calcium in the soil, and since the other soil properties also depend on this ratio, the accuracy of the prediction of any parameter λ can often be improved by adding another variate. This improvement is presumably due to the other variate being able to correct for the different hydration properties and the different proportions of the exchangeable bases in the soil. Table L shows the extent to which the residual variance of a variate λ from the $\lambda.B$ regression can be reduced by adding a second independent variate.

Table L. *Efficiency of variates in increasing the accuracy of B predictions.*

λ	$\mu =$	$[(1 - R^2_{\lambda.B}) - (1 - R^2_{\lambda.B\mu})]$					$1 - R^2_{\lambda.B}$
		M	v'_s	p'_s	X	I	
h		0.0175	0.0025	0.0036	0.0210	0.0043	0.0817
w'		0.0086	0.0000	0.0197	0.0093	0.0108	0.0592
S		0.0165	0.0009	0.0185	0.0113	0.0222	0.1133
I		0.0368	0.0000	0.0237	0.0314	—	0.1405

Considering the prediction of h and w' only, neither of these regressions can be increased very much over and above the two-term regression formula, for

$$\begin{aligned}
 1 - R^2_{h.BX} &= 0.0607, & 1 - R^2_{h.BXv'} &= 0.0564, & 1 - R^2_{h.BXv'CM} &= 0.0561, \\
 \text{decrease due to} && v' &= 0.0037, & C \text{ and } M &= 0.0003, \\
 1 - R^2_{w'.Bp_s} &= 0.0395, & 1 - R^2_{w'.Bp_sI} &= 0.0369, & 1 - R^2_{w'.Bp_sIX} &= 0.0369, \\
 \text{decrease due to} && I &= 0.0034, & X &= 0.0000.
 \end{aligned}$$

304 *Significance of Certain "Single Value" Soil Constants*

In each case the residual variance is greater than can be accounted for by experimental error alone. It is worth noting, in passing, that B cannot be predicted within the limits of experimental error from other variates, although it can be computed with considerable accuracy, for

$$1 - R^2_{B \cdot hw'} = 0.0434, \quad 1 - R^2_{B \cdot hw'Sv'} = 0.0364,$$

decrease due to

$$S \text{ and } v' = 0.0070.$$

Table LI gives the standard deviation s_1 between the observed value of any one of the variates h , w' or B and its value predicted from the multiple regression equations just considered; and the standard deviation s_2 between the observed value of the variate and its predicted value which is due to errors in the measurements of the variates used in the prediction formula. The table also gives the means and the standard deviations s_3 calculated from the divergences between duplicates.

Table LI. *Accuracy of the prediction formulae for B , h , w' .*

	Mean	s_1	s_2	s_3
B	17.97	1.35	0.57	0.49
h	3.064	0.33	0.09	0.03 ¹
w'	51.09	2.58	1.21	1.08

In general, the differences between the calculated and observed values of the variates lie within twice the standard deviation due to experimental errors alone.

In conclusion, the main result arrived at for these Natal soils is that such variates as h , w' and S are determined very largely by the total amount of exchangeable bases held by the soil, and only to a small extent by other terms. Since it is almost certain that in the series under consideration both the proportion of exchangeable bases and the type of clay varied from soil to soil, the other terms in the multiple regression equation probably allow for these two factors.

SUMMARY AND CONCLUSIONS.

The conclusions that have been arrived at from the foregoing statistical examination of the available data on the physical properties of the Natal soils used by Coutts are:

(1) The base exchange capacity of the soil, as measured by Schofield's potassium phosphate buffer method, appears to be of predominant importance for predicting several of the soil properties, as for example

¹ Estimated, this determination was not made in duplicate, but the figure given is that found for h determined on the peroxide-treated soils.

the sticky point and the moisture content at 50 per cent. relative humidity. On the other hand, the clay content seems to be of quite minor importance in predicting these soil properties.

(2) The information from the data supplied by the Keen-Raczkowski box indicates that w , the weight of water held per gram of soil in the box is very closely correlated with the base exchange capacity of the soil, while the swelling and pore-space parameters are more complex. The swelling v seems to be dependent on the base exchange capacity of the soil and a term probably representing the structure of the soil, while the pore space p seems to be dependent on the clay content and a soil structure term. By choosing an appropriate definition of the pore space practically all the structure information given by the swelling parameters is contained in it.

(3) The xylene equivalent measures a property of the soil that is independent of the organic matter present, and can be almost completely predicted from parameters determined on the soil after it has been boiled with hydrogen peroxide. It is more completely determined than any other variate by the amount of clay and silt in the soil, though this prediction is not strikingly good. The moisture equivalent can be predicted with great accuracy from the xylene equivalent and the base exchange capacity of the soil.

(4) The amount of imbibitional water in the soil, as determined from the moisture equivalent and the xylene equivalent, is of only limited value as a prediction variate. The two primary variates are always considerably better. It is fairly closely related to the base exchange capacity of the soil, but the whole theory underlying its determination is so doubtful that it is impossible to give any exact meaning to the quantity so determined.

In conclusion it appears that if the box parameters and the xylene equivalent were given for the Natal soils, none of the other parameters would add very much extra information. The loss on ignition has not been studied in very great detail because an extensive preliminary examination of its properties, and particularly of the ignition losses of the natural and the peroxide-treated soils, gave results of no great importance.

In conclusion the author wishes to acknowledge his indebtedness to Dr B. A. Keen for the many valuable discussions he has had with him during the course of this work.

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APPENDIX.

THE COMPUTATION OF MULTIPLE REGRESSION AND
CORRELATION COEFFICIENTS.*Method I. Multiple correlation coefficients only.*

If $r_{x_i x_j}$ is the correlation coefficient between the variables x_i and x_j , and if $R_{y \cdot x_1 x_2 \dots x_n}$ is the multiple correlation coefficient of the variable y with the n variables $x_1, x_2 \dots x_n$, then

$$1 - R_{y \cdot x_1 x_2 \dots x_n}^2 = \frac{\begin{vmatrix} 1 & r_{yx_1} & r_{yx_2} & \dots & r_{yx_n} \\ r_{yx_1} & 1 & r_{x_1 x_2} & \dots & r_{x_1 x_n} \\ r_{yx_2} & r_{x_1 x_2} & 1 & \dots & r_{x_2 x_n} \\ \dots & \dots & \dots & \dots & \dots \\ r_{yx_n} & r_{x_1 x_n} & r_{x_2 x_n} & \dots & 1 \end{vmatrix}}{\begin{vmatrix} 1 & r_{x_1 x_2} & \dots & r_{x_1 x_n} \\ r_{x_1 x_2} & 1 & \dots & r_{x_2 x_n} \\ \dots & \dots & \dots & \dots \\ r_{x_1 x_n} & r_{x_2 x_n} & \dots & 1 \end{vmatrix}}.$$

Using two independent variables only, this reduces to

$$1 - R_{y \cdot x_1 x_2}^2 = \frac{(1 - r_{yx_2}^2)(1 - r_{x_1 x_2}^2) - (r_{yx_1} - r_{yx_2} r_{x_1 x_2})^2}{1 - r_{x_1 x_2}^2}.$$

This expression can be evaluated very rapidly on a calculating machine, for if r and $1 - r^2$ are tabulated, $-(r_{yx_1} - r_{yx_2} r_{x_1 x_2})^2$ can be evaluated, and to this $(1 - r_{yx_2}^2)(1 - r_{x_1 x_2}^2)$ added by setting $(1 - r_{x_1 x_2}^2)$ on the keyboard and multiplying by $(1 - r_{yx_2}^2)$, and the sum divided by $(1 - r_{x_1 x_2}^2)$, which is already on the keyboard, gives $1 - R^2$ without any intermediate figures being written down.

If there are more than two independent variables, the determinants must be evaluated, and the most convenient method to do this is due to Aitken¹. If

$$| a_1 b_2 c_3 | \equiv \begin{vmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & c_3 \end{vmatrix}$$

the method depends on the theorem of compound determinants that

$$| | a_1 b_2 c_3 | | | b_2 c_3 d_4 | | \div | b_2 c_3 | = | a_1 b_2 c_3 d_4 |$$

The steps in the computation are as follows. The determinant, which is symmetrical about the diagonals, is written down.

DETERMINANT I.

$$\begin{array}{ccccccc} 1 & (b) & r_{yx_1} & r_{yx_2} & r_{yx_3} & \dots & r_{yx_n} & (c) \\ & & 1 & r_{x_1x_2} & r_{x_1x_3} & \dots & r_{x_1x_n} & \\ & & & 1 & r_{x_2x_3} & \dots & r_{x_2x_n} & \\ & & & & 1 & \dots & r_{x_3x_n} & \\ & & & & & \dots & 1 & (d) \end{array}$$

The last entry, unity in this case, is chosen as pivotal element, and all minors of the second order containing this element are written down. The first entry is simply

$$\text{term } (a) \times \text{term } (b) - \text{term } (c) \times \text{term } (d)$$

in the above determinant. Term (a) is the same all through the subsequent calculation, term (b) is in succession every term not contained in the last row or the last column, term (c) is the term in the last column in the same row as term (b), and term (d) is the term in the last row in the same column as term (b). The second determinant, which is also symmetrical about the diagonal, is thus

DETERMINANT II.

$$\begin{array}{ccccccc} 1 - r_{yx_n}^2 & r_{yx_1} - r_{yx_n} r_{x_1x_n} & \dots & r_{yx_{n-1}} - r_{yx_n} r_{x_{n-1}x_n} & & & \\ & 1 - r_{x_1x_n}^2 & \dots & r_{x_1x_{n-1}} - r_{x_1x_n} r_{x_{n-1}x_n} & & & \\ & & \dots & & & & \\ & & & 1 - r_{x_{n-1}x_n}^2 & & & \end{array}$$

The next step consists in taking $1 - r_{x_{n-1}x_n}^2$, the last element, as pivotal and repeating the process. The whole process is repeated until only one term is left. The terms so computed are not the determinants wanted,

¹ *Trans. Fac. Act. (1931)*, 13, 272-5, also *Proc. Roy. Soc. Edin.* (in the Press).

308 Significance of Certain "Single Value" Soil Constants

since no division has yet been carried out. Each term in determinant III should have been divided by the pivotal element of determinant I, namely unity, each term in determinant IV by the pivotal element of determinant II, namely $1 - r^2_{x_{n-1}x_n}$, and so on. If L_1 is the pivotal element of determinant I, L_2 of determinant II, etc., then each term of determinant III should be divided by L_1 , of determinant IV by $L_1^2 L_2$, of determinant V by

$$\frac{(L_1^2 L_2)^2 L_3}{L_1} = L_1^3 L_2^2 L_3,$$

and so on. If the last three calculated determinants are

$$\begin{vmatrix} A & B & C \\ & D & E \\ & & L_{n-1} \end{vmatrix}, \quad \begin{vmatrix} G & H \\ & L_n \end{vmatrix}, \quad K,$$

the appropriate divisors are

$$L_1^{n-3} L_2^{n-4} \dots L_{n-4}^2 L_{n-3},$$

$$L_1^{n-2} L_2^{n-3} \dots L_{n-3}^2 L_{n-2},$$

$$L_1^{n-1} L_2^{n-2} \dots L_{n-2}^2 L_{n-1},$$

so that

$$\begin{aligned} 1 - R^2_{y \cdot x_1 x_2 \dots x_n} &= \frac{K}{L_1^{n-1} L_2^{n-2} \dots L_{n-2}^2 L_{n-1}} \div \frac{L_n}{L_1^{n-2} L_2^{n-3} \dots L_{n-3}^2 L_{n-2}} \\ &= \frac{K}{L_1 L_2 \dots L_{n-1} L_n}, \end{aligned}$$

and similarly

$$1 - R^2_{y \cdot x_2 x_3 \dots x_n} = \frac{G}{L_1 L_2 \dots L_{n-1}},$$

$$1 - R^2_{y \cdot x_3 x_4 \dots x_n} = \frac{A}{L_1 L_2 \dots L_{n-2}},$$

so that this method gives in succession

$$1 - R^2_{y \cdot x_{n-1} x_n}, \quad 1 - R^2_{y \cdot x_{n-2} x_{n-1} x_n} \dots 1 - R^2_{y \cdot x_3 x_4 \dots x_n}, \quad 1 - R^2_{y \cdot x_1 x_2 \dots x_n}$$

with no more computing than is required for the last multiple correlation coefficient. Hence, by arranging the order of the variates so that x_n is the most important, and the others following in decreasing order of importance, it is quite straightforward to discover when terms are ceasing to add significantly to the multiple regression.

Method II. Multiple regression and correlation coefficients.

If the individual correlation coefficients have not been evaluated, or if the regression coefficients themselves are wanted, the following method is applicable. Let

$$Y = b_1x_1 + b_2x_2 + \dots + b_nx_n,$$

where all the x 's and Y are measured from their mean values, so that $x_1 = (x_1 - \bar{x}_1)$. The b 's are determined in such a way that $\Sigma (y - Y)^2$ shall be a minimum, and are given by

$$b_1 = \left| \begin{array}{ccc} \Sigma x_1 y & \Sigma x_1 x_2 \dots \Sigma x_1 x_n \\ \Sigma x_2 y & \Sigma x_2 x_2 \dots \Sigma x_2 x_n \\ \dots \dots \dots \\ \Sigma x_n y & \Sigma x_n x_2 \dots \Sigma x_n x_n \end{array} \right| \div \left| \begin{array}{ccc} \Sigma x_1 x_1 & \Sigma x_1 x_2 \dots \Sigma x_1 x_n \\ \Sigma x_1 x_2 & \Sigma x_2 x_2 \dots \Sigma x_2 x_n \\ \dots \dots \dots \\ \Sigma x_1 x_n & \Sigma x_2 x_n \dots \Sigma x_n x_n \end{array} \right|$$

and

$$\Sigma (y - Y)^2 = \left| \begin{array}{ccc} \Sigma y y & \Sigma y x_1 \dots \Sigma y x_n \\ \Sigma y x_1 & \Sigma x_1 x_1 \dots \Sigma x_1 x_n \\ \dots \dots \dots \\ \Sigma y x_n & \Sigma x_1 x_n \dots \Sigma x_n x_n \end{array} \right| \div \left| \begin{array}{ccc} \Sigma x_1 x_1 & \Sigma x_1 x_2 \dots \Sigma x_1 x_n \\ \Sigma x_1 x_2 & \Sigma x_2 x_2 \dots \Sigma x_2 x_n \\ \dots \dots \dots \\ \Sigma x_1 x_n & \Sigma x_2 x_n \dots \Sigma x_n x_n \end{array} \right|$$

and

$$1 - R^2_{y \cdot x_1 x_2 \dots x_n} = \frac{\Sigma (y - Y)^2}{\Sigma y^2}.$$

The first step is to solve the symmetrical determinant which is the numerator of $\Sigma (y - Y)^2$, just as the previous determinant was solved. This gives as before the whole series of values of $\Sigma (y - Y)^2$ as each new variate is added. To obtain the regression coefficients, if the last three determinants are

$$\left| \begin{array}{ccc} A & B & C \\ & D & E \\ & & F \end{array} \right|, \quad \left| \begin{array}{cc} G & H \\ & I \end{array} \right|, \quad K$$

with divisors

$$\Delta_1, \quad \Delta_2, \quad \Delta_3,$$

then since

$$H = \Delta_2 \left| \begin{array}{ccc} \Sigma y x_1 & \Sigma x_1 x_2 \dots \Sigma x_1 x_n \\ \Sigma y x_2 & \Sigma x_2 x_2 \dots \Sigma x_2 x_n \\ \dots \dots \dots \\ \Sigma y x_n & \Sigma x_n x_2 \dots \Sigma x_n x_n \end{array} \right| \text{ and } I = \Delta_2 \left| \begin{array}{ccc} \Sigma x_1 x_1 & \Sigma x_1 x_2 \dots \Sigma x_1 x_n \\ \Sigma x_1 x_2 & \Sigma x_2 x_2 \dots \Sigma x_2 x_n \\ \dots \dots \dots \\ \Sigma x_1 x_n & \Sigma x_2 x_n \dots \Sigma x_n x_n \end{array} \right|$$

clearly

$$b_1 = \frac{H}{I},$$

since the common divisor drops out. Continuing this method of solution,

$$D b_1 + E b_2 = B,$$

310 *Significance of Certain "Single Value" Soil Constants*

and so on, giving each b in succession. If, however, the standard deviations of the b 's are wanted, the c -matrix described by Fisher (6) in § 29, must be evaluated instead. For this the top line of each determinant is ignored, and the solution proceeds exactly as described by Fisher. Using L 's to denote the last term of each determinant,

$$c_{11} = \frac{L_1 L_2 \dots L_{n-2} F}{I}, \quad Ec_{11} + Fc_{12} = 0, \quad Dc_{12} + Ec_{22} = L_1 L_2 \dots L_{n-2}.$$

In both these methods there is a final check that

$$\Sigma (y - Y)^2 = b_1 \Sigma x_1 y + b_2 \Sigma x_2 y + \dots + b_n \Sigma x_n y.$$

The advantage of the methods outlined is that if, for example, it was found that the variates x_1 and x_2 did not contribute significantly to the regression, the values of the regression coefficients in

$$Y = b_3 x_3 + b_4 x_4 + \dots + b_n x_n$$

can be determined by ignoring the last two determinants and the second and third rows and columns in all the others, and proceeding as before. Also if it is found that b_2 and b_3 could be ignored without b_1 , it needs only a little extra recalculation of the original determinants to determine $b_1, b_4 \dots b_n$, but it is essential that x_n and x_{n-1} should be the important variables.

(Received February 9th, 1933.)

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RAPID METHODS OF EXAMINING SOILS.

II. THE USE OF *p*-NITROPHENOL FOR ASSESSING LIME STATUS.

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IN the course of an investigation of the base exchange capacity of soils, of which the results will shortly be published, use has been made of a number of buffer solutions made up by dissolving in lime water double the amount of an organic acid required for neutralisation. The acids selected were those which have soluble calcium salts. If to one of these solutions is added a small quantity of soil, the soil rapidly takes up the *pH* of the solution. In doing so it takes lime from the solution if it was originally more acid, and gives up lime and other bases to the solution if it was originally more alkaline. Provided the lime taken up from or given to the solution is not too large a fraction of the total lime originally in the solution, the *pH* of the solution is not appreciably changed, and the lime lost or gained by the solution is a measure of the lime that must be given to or taken from the soil to bring it to the final *pH*. An organic acid, which is likely to be of particular value in routine work, is *p*-nitrophenol, which, when half-neutralised, has a *pH* close to 7. The quantity of lime needed to bring an acid soil to the neutral point can therefore be found very rapidly as follows:

A winchester of distilled¹ water is shaken with excess of lime and allowed to stand for 24 hours. The normality is determined by titration, and sufficient is placed in a litre measuring flask, or stoppered measuring cylinder, to give a solution *N*/25 in calcium when water is added to the mark. Before the water is added, 8.34 gm. of *p*-nitrophenol is added and allowed to dissolve. The lime is sufficient to neutralise two-thirds of the *p*-nitrophenol.

When it is anticipated that something less than 8 mg. equivalents of lime will be taken up per 100 gm. of soil, 8 gm. of the air-dry soil are placed in a 50 c.c. boiling tube and 40 c.c. of the solution is added. After an overnight period in a shaker, it is filtered², care being taken to avoid evaporation, and 25 c.c. is titrated with *N*/20 HCl, using bromocresol green as indicator. The titration is taken to the point at which the

¹ Tap water can be used.

² In many cases the supernatant liquid, after a few hours' standing, is clear enough to be pipetted off without filtration.

green colour has almost disappeared. The flask in which the titration was done is set on one side, and 25 c.c. of the original solution titrated to the same colour. This can be done to one drop. The difference in cubic centimetres between the two titrations equals the milligram equivalents of lime taken up per 100 gm. of soil.

The "ideal" value for this weight of soil is 5 mg. equivalents per 100 gm., as when 8 gm. of such a soil is added to 40 c.c. of the solution, the solution left in contact with it is exactly half-neutralised. Where a soil gives a value between 8 and 15, only 4 gm. should be used, and the number of cubic centimetres must be multiplied by 2 to reduce the figure to milligram equivalents per 100 gm. of soil. From 15 to 30, 2 gm. only are needed, and so on. The aim should be to adjust the weight so that the solution after contact with the soil is substantially half-neutralised. As the solution is strongly buffered in this region, a discrepancy of 25 per cent. in the lime content of the solution only alters the pH by 0.2. The $N/20$ HCl solution is the only one which requires careful standardisation.

It is not essential to have the soil continuously shaken with the solution for 16 hours, but it is important to have a *contact* of at least this duration, especially in the case of organic soils. A gentle shaking somewhat improves the reproducibility. With a longer contact, a little more lime is usually taken up. Sixteen hours does not therefore give a final figure, but is convenient, since a variation of an hour or so does not materially influence the result. When the lime uptake is large, duplicates usually fall within 2 per cent. of the mean, or within 0.2 mg. equivalents where it is small.

The merits of the method that will appeal to practical soil investigators are:

- (1) its rapidity;
- (2) its simplicity;
- (3) the cheapness of the reagents and apparatus needed;
- (4) the absence of any personal factor.

It is best to avoid the term "lime requirement," since crops do not in general "require" a neutral soil. This fact does not, however, destroy the value of such a test. Moreover, other pH values can be used by changing the acid,

Acid	Half-neutralised at pH
Acetic	4.6
<i>p</i> -nitrophenol	7.1
phenol	9.8

and the range can be further widened by increasing the concentration of the acids where solubility permits. In the case of acetic acid, titration

with HCl is not feasible, but a sharp end-point is obtained with $N/20$ alkali, using thymol blue as indicator. The same procedure permits a determination to be made of the bases dissolved from the soil by $N/20$ HCl, as, from the curves of Britton (1), it appears that all the alumina and iron are precipitated at the alkali turning point of thymol blue (pH 8–9), and so are not reckoned in with the “bases.”

The possibilities of other acids are being explored, and the factors which affect the equilibrium between the soil and the solution, such as time of contact, temperature and salt content, are being studied. Although time is needed to realise the full possibilities of the method, the value of p -nitrophenol is already clear. The purpose of this note is to draw the attention of soil workers to this substance, and to suggest that they give it a trial in their soil reaction studies. In using the routine method suggested above, the process of adjusting the weight of soil used according to the lime uptake of the soil is not as troublesome as it might seem at first sight. A convenient practice is to make up two tubes, one containing twice as much soil as the other. The two titrations serve as a check on one another and, where necessary, the figure corresponding to the “ideal” weight which would give a 5 c.c. difference can usually be found by interpolation or extrapolation. When investigating sour soils in this way, 4 and 8 gm. are usually satisfactory for heavy samples, while 8 and 16 gm. may prove more suitable for light samples. Neutral or nearly neutral soils are better studied with the aid of a solution containing only three-quarters the quantity of lime, but such measurements are, in the nature of things, not so often needed.

The p -nitrophenol method may also be applied to soils which have been leached, first with dilute (say $N/20$) HCl, and then with water. In this way a measure is obtained of the exchangeable base content at pH 7. By using other acids, the content at a series of pH values can be found. This aspect of the method will be discussed more fully in a subsequent paper.

SUMMARY.

By the use of a solution of p -nitrophenol in lime water a rapid and simple measurement can be made of the lime taken up by a soil sample in reaching neutrality. The same method applied to acid-washed samples gives the exchangeable base content at pH 7.

REFERENCE.

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(Received February 9th, 1933.)

RAPID METHODS OF EXAMINING SOILS.

III. THE USE OF DIHYDROGEN POTASSIUM PHOSPHATE IN STUDYING BASE EXCHANGE CAPACITY.

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WHEN a solution containing dipotassium hydrogen phosphate comes in contact with soil, calcium and magnesium ions originally attached to the soil are precipitated as insoluble phosphate. If the soil was acid with respect to the solution, hydrogen ions from the soil combine with some of the HPO_4'' ions, forming $\text{H}_2\text{PO}_4'$ ions. In either case an equivalent number of potassium ions become attached to the soil. If this were the only reaction taking place, and if all the exchangeable calcium and magnesium were precipitated, the potassium removed from the solution would give the amount of base held by the soil at the $p\text{H}$ of the solution less the exchangeable potassium and sodium originally present in the soil. By making use of the fact that the HPO_4'' and $\text{H}_2\text{PO}_4'$ ions have nearly the same electrical mobility, the uptake of potassium can be found to a close approximation by measuring the change in the electrical conductivity of the solution.

This method is likely to prove useful when texture figures are needed on a large number of soils of similar nature. When the work is organised, one man can easily make forty measurements in a day, including the necessary weighings. This estimate does not include the time needed for the preparation and sampling of the soil which is just the same as for mechanical analysis. The method is free from personal judgment, such as is needed in measuring the "sticky point," and can be applied, without the need for preliminary treatment, to any soil, calcareous or non-calcareous, which does not contain large amounts of exchangeable sodium or potassium or of soluble salts. Small quantities of calcium salts, such as are normally present, do not interfere.

A statistical analysis of some results obtained is given in a paper by Mr E. W. Russell in this issue of the *Journal*¹, which indicates the relationship between "base exchange capacity" thus determined and other properties of the particular set of soils examined. These determinations

¹ See pp. 261-310.

were made with a solution 0.1 molar in K_2HPO_4 and 0.05 molar in KH_2PO_4 . The KH_2PO_4 does not enter into the main reactions but stabilises the pH, which was just below 7. A weighed quantity of soil, sufficient to take up about 1 mg. equivalent of potassium, was placed in a 50 c.c. "pyrex" boiling tube, and 25 c.c. of the solution was added. The tube was shaken for 1 hour and then placed in a water bath. The conductivity was determined with the aid of an A.C. bridge and dip electrodes of platinised platinum which were lowered into the clear (or almost clear) supernatant liquid. A tube containing some of the original solution was also placed in the water bath and measured. The current was supplied by a valve oscillator at about 2000 cycles, and a two-stage valve amplifier and headphones were used as detector. A small variable condenser across the measuring resistance enabled readings to be made to four places without difficulty. An actual example will make the method of computation clear.

In this case, the resistance reading for the original solution was 20.49, while after contact with 7 gm. of the soil it was 24.68. The fractional change in *conductivity* was, therefore,

$$(24.68 - 20.49)/24.68 = 0.170.$$

The solution was originally 0.25 normal in potassium; thus 25 c.c. originally contained 6.25 mg. equivalents. Seven grams of soil therefore took up $6.25 \times 0.170 = 1.063$ mg. equivalents of potassium, so that 100 gm. would have taken up 15.2. The resistance is, of course, influenced by temperature, but as the two tubes were side by side in the same water bath, and only a ratio of resistances is required, the temperature does not influence the final result.

It has been assumed in this calculation that the fractional change in conductivity is exactly equal to the fractional change in potassium concentration. This is very close to the truth for the exchange of hydrogen and potassium, as the slightly lower mobility of the H_2PO_4' ion in relation to that of the HPO_4'' ion almost exactly offsets the change in equivalent conductivity due to concentration. This can easily be demonstrated if the action of an acid soil in exchanging hydrogen for potassium is imitated by the addition of 0.15 molar H_3PO_4 to the standard mixture of K_2HPO_4 and KH_2PO_4 . The fractional decrease in the potassium concentration is equal to the number of cubic centimetres of acid added divided by the total volume. Table I shows the result of such a test, which indicates that, on an average, an error of scarcely more than 1 per cent. is caused by using a factor of unity.

Table I (*Temp.* = 25.0° C.).

c.c. of 0.15 molar H_3PO_4 added to 18 c.c. of standard mixture	Fractional change in potassium concentration	Resistance ohms	Fractional change in conductivity	Factor
0	—	20.24	—	—
1	0.0527	21.37	0.0528	0.998
3	0.1429	23.64	0.1438	0.994
5	0.2174	26.00	0.2212	0.983
7	0.2800	28.34	0.2859	0.979

The action of soil in exchanging calcium or magnesium for potassium is imitated by adding to the standard mixture a solution of H_3PO_4 of strength one-sixth of 0.15 = 0.025 molar. In this way the concentration of KH_2PO_4 remains constant, while that of the K_2HPO_4 is reduced.

Table II (*Temp.* = 24.8° C.).

c.c. of 0.025 molar H_3PO_4 added to 18 c.c. of standard mixture	Fractional change in potassium concentration	Resistance ohms	Fractional change in conductivity	Factor
0	—	20.36	—	—
2	0.1000	22.29	0.0867	1.153
4	0.1818	24.23	0.1596	1.139
6	0.2500	26.10	0.2200	1.136
8	0.3077	28.04	0.2738	1.124

From Table II it is evident that in this case the fractional change in conductivity has to be increased by about 14 per cent. to obtain the fractional change in potassium concentration.

With a set of calcareous soils this 14 per cent. correction might be applied, but where the figures are only to be compared one with another no real purpose would be served. In general, a separate measurement would be needed to decide the amount of the correction, so that for the present it seems best to use the figures obtained in the way indicated above as they stand.

The adequacy of the conductivity method for determining the potassium lost by the solution can be further checked by comparing figures computed in this way with those obtained by chemical analysis. The potassium remaining in 5 c.c. of filtrate may be determined volumetrically by first adding 10 c.c. of $N/20$ KOH, and titrating with $N/20$ HCL till thymol blue just loses its blue colour; and then adding bromocresol green, and continuing the titration till the green colour just disappears. If these readings are compared with similar ones for 5 c.c. of the original mixture, the amount by which the first reading has been decreased by contact with the soil is $1/20$ the number of millimoles of KH_2PO_4 that

have been *added* to the 5 c.c., while the decrease in the second reading is $1/20$ the number of millimoles of K_2HPO_4 *removed*. The equivalents of potassium removed can thus be obtained by subtracting the first decrease from twice the second and dividing by 20. This must then be multiplied by 500 and divided by the weight of soil that was placed in 25 c.c. of the standard mixture in order to obtain the answer in milligram equivalents per 100 gm. of soil. These titrations must be done very carefully if reasonably accurate figures are to be obtained; with practice, the end-points can be judged to one drop unless the filtrate is very strongly coloured by humic matter.

The results of such a comparison are shown in Table III, columns 3 and 4. The agreement is rather closer than was to be anticipated. Of the two methods, the analytical one is less precise, and a small systematic error may arise from the coloration of the solutions by humic matter. The absence of agreement in the case of the very acid soil 1 is to be expected in view of the removal of phosphoric acid.

Table III.

Soil No.	pH	Mg. equivalents potassium removed by 100 gm. soil		Millimoles phosphoric acid removed by 100 gm. soil	Mg. equivalents N/20 HCl neutralised by 100 gm. soil	Mg. equivalents lime taken up from neutral buffer solution by 100 gm. acid washed soil
		Conductivity method (uncorrected)	Titration method			
1	3.5	26.1	27.1	6.95	4.6	23.6
2	4.5	15.6	16.3	6.55	9.1	17.6
3	5.2	15.4	16.0	7.15	15.1	18.9
4	*	11.0	12.4	8.4	—	13.2
5	*	14.5	15.1	9.6	—	15.8
6	*	13.9	14.6	8.4	—	17.0

* Calcareous soils: soils 1, 2, 3 from Rothamsted Park Grass Plots 9, 7 and 14 (all unlimed); soils 4, 5, 6 from Broadbalk Field Rothamsted Plots 5, 18 and 2.

The amount of phosphoric acid removed by 100 gm. of soil was obtained taking $1/20$ of the amount by which the decrease in the second titration figure exceeded the decrease in the first and multiplying by 500 over the weight of soil. The outstanding point to notice is that in the case of soil No. 1, if this phosphoric acid had been removed from the solution as $CaHPO_4$ or $MgHPO_4$ this would have involved the removal of 13.9 mg. equivalents of exchangeable calcium and magnesium. Now this soil is extremely acid, and when shaken with $N/20$ HCl only 4.6 mg. equivalents of acid are neutralised per 100 gm. of soil. The exchangeable calcium and magnesium cannot possibly exceed this figure. The explanation that suggests itself is that most of the 6.95 millimoles of phosphoric acid are

removed as a complex in which KH_2PO_4 is combined (possibly with alumina). It is not at all improbable that the same action proceeds to a less extent in the case of the neutral soils, and that it helps to compensate for a fraction of the exchangeable calcium and magnesium which remains in the soil.

However this may be, the net result is that with very acid soils the potassium removed from solution usually exceeds the amount of lime which the soil, after acid washing, will remove from a buffer solution at pH 7: the discrepancy occasionally amounting to 20 per cent. With neutral soils, the potassium removed is usually a little less, so that when the conductivity method is used the result may be up to 20 per cent. too low. The discrepancy varies with the nature of the soil as well as with the degree of acidity, so that a pH determination would not serve to determine it with accuracy. At the same time, it should be recorded that no case has yet been found where the discrepancy exceeds 30 per cent., although the examination has included soils of widely different origin and composition. The agreement in most cases is close. Nevertheless, the search for exceptions is still being pursued.

EXPERIMENTAL DETAILS.

The absolute magnitude of the resistance naturally depends on the dimensions and spacing of the measuring electrodes. The electrodes used by the author are square foils 1×1 cm. and spaced 1 cm. apart; they are protected by a glass sheath which slides easily inside the boiling tubes.

The standard mixture can be made up by mixing two volumes of 0.15 molar K_2HPO_4 with one volume of 0.15 molar KH_2PO_4 . The solution of 0.15 molar KH_2PO_4 can be made up by weighing out the recrystallised salt. K_2HPO_4 is hygroscopic, so that the 0.15 molar K_2HPO_4 solution, if made up by dissolving the salt, must be checked as to its strength by titration with acid, using bromocresol green, the exact tint required for the end-point being most easily judged by placing some indicator in a KH_2PO_4 solution for comparison. Alternatively, the mixture can be made by adding equal volumes of 0.5 molar KOH and 0.3 molar H_3PO_4 .

The figures used by Mr Russell in the paper cited were collected from data obtained over a period of several months, and were not obtained from a single batch of measurements made specially for the purpose. This largely accounts for the rather high figure, 2.8 per cent., for the

standard deviation of the mean of two laboratory measurements. In a more recent set of 128 pairs of laboratory measurements of soil samples taken from a single field, the standard deviation was only 0.8 per cent. This improvement is due, in part, to the adoption of a "guard tube" technique, in which the electrode is first dipped into a duplicate tube before being placed in the one to be measured, so that any solution transferred is of the same composition.

The method, as well as the time of shaking, and probably also the temperature, affect the results to a small extent; so that comparison is most precise between tubes shaken simultaneously in a mechanical shaker.

Potassium carbonate behaves similarly to dipotassium hydrogen phosphate, and has the advantage that its potassium can be determined by a single direct titration. This solution is being examined, as it may find applications where a conductivity bridge is not available. Although rapid by comparison with other methods, the titration takes three or four times as long as a conductivity measurement.

SUMMARY.

The reduction in the electrical conductivity of a mixed solution of K_2HPO_4 and KH_2PO_4 caused by the addition of soil is a measure of the potassium uptake, and is therefore an indication of the "base exchange capacity" of the soil at *pH* 7. Two disturbing factors are noted, and it is concluded that the method is likely to be most useful where a rapid comparison of soils of a similar nature and *pH* is required.

(Received February 9th, 1933.)

SOME ASPECTS OF THE PHYSIOLOGY OF CERTAIN NITRITE-FORMING BACTERIA

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DURING the course of work carried out for the Department of Scientific and Industrial Research, as part of the programme of the Water Pollution Research Board, on the purification of waste waters from a beet sugar factory by biological filtration it was found that comparatively large quantities of nitrite were produced in the filters. A large number of bacterial strains, which had been isolated from such filters, were therefore tested upon media containing various ammonium salts to see whether among them there were any which could convert ammonia into nitrite. It was found that out of 229 species of bacteria which were tested 104 produced nitrite from ammonium salts to some extent, and in behaviour were very similar to those already isolated from soil by Cutler and Mukerji(1).

The results given in this paper were obtained from a survey of the whole bacterial population which was carried on over two seasons, and detailed results regarding individual species and their morphological and physiological characters are not in a sufficiently advanced stage in the majority of cases to be given here.

The filters at the beet sugar factory were in general principle similar to those used in sewage work and the medium of which they were constructed was either gravel or clinker. Infection from the air could easily occur, and the waste water from the factory also contained large numbers of micro-organisms from the soil which was introduced with the roots of the sugar beets. The usual practice in such factories is to concentrate the work into a short period of 90 to 100 days, and there is therefore a long period from the end of one season to the beginning of the next when the filters stand dry and idle. Further descriptions of the filters and of the biochemical changes which the solution undergoes in its passage through them are given by Jenkins(2) and Barritt(3). The nitrifying bacteria in question appear to be very catholic as regards their reactions; the same species may be capable not only of forming nitrite but also of

causing it to disappear, nitrite may also be formed from urea, and by the reduction of nitrate, nor have the conditions under which these changes take place yet been definitely determined. It is obvious therefore that much work remains to be done, but at the same time a preliminary communication outlining the types of behaviour exhibited may be of interest to those working on similar problems.

METHODS.

In the course of routine examination of the bacterial strains one of the tests employed was to inoculate the cultures into ammonium sulphate in mineral salt solution¹ to which 0.1 per cent. of different carbohydrates had been added. The carbohydrates were sucrose, dextrose, laevulose, lactose, maltose, galactose and mannitol. The formation of acid and gas was recorded, and the nitrite present was estimated by the Griess-Ilosva method (4).

Those cultures giving a nitrite reaction were then further tested on the following additional ammonium salts: phosphate, carbonate, acetate and lactate.

RESULTS.

The different strains isolated from the filters fall into three groups, the first comprising those which produced acid and gas on one or more of the carbohydrates, the second those producing acid but no gas, and the third, those giving no reaction of this type in spite of their growth. Table I gives the numbers of nitrite and non-nitrite forming bacterial species which produced acid on one or more of the carbohydrates. All species are omitted which only occurred sporadically on the filters.

Table I.

Numbers of carbohydrates from which acid was formed by nitrifying and non-nitrifying bacteria.

Type of bacteria	Number of carbohydrates							
	0	1	2	3	4	5	6	7
Nitrite forming 1st season	15	10	9	5	1	0	1	0
Non-nitrite forming 1st season	19	25	13	17	7	1	2	2
Nitrite forming 2nd season	3	6	3	9	12	16	9	5
Non-nitrite forming 2nd season	3	4	4	5	1	7	9	6

¹ The composition of the medium was as follows: 1.0 gm. $(\text{NH}_4)_2\text{SO}_4$, 0.6 gm. NaCl, 0.02 gm. CaCl_2 , 0.005 gm. MgSO_4 , 0.3 gm. K_2HPO_4 , 1000 c.c. H_2O .

The results of the first season suggest that on the whole the bacteria in the filters were species which were comparatively inert on the carbohydrates, only a small percentage being able to utilise more than four; the second season's work, however, contradicted this idea, although the conditions of infection and of growth were the same in both years. It is interesting that there was no difference to be observed in the behaviour of nitrifying and non-nitrifying bacteria upon carbohydrates, although the nitrifying forms are not usually regarded as organisms which obtain energy from carbohydrate decomposition.

The comparative popularity of the carbohydrates employed is shown in Table II where the numbers include both nitrifiers and non-nitrifiers.

Table II.

Percentage numbers of bacteria forming acid on different carbohydrates.

No acid	Sucrose	Lactose	Dextrose	Galactose	Laevulose	Maltose	Mannitol
17.4	37.1	28.8	44.9	46.7	49.7	34.5	34.8

As would be expected from their place of origin it is a small percentage which are wholly without action on the carbohydrates.

Nitrite formation on different ammonium salts.

The strains were then tested as to their nitrifying power on the following ammonium salts: carbonate, phosphate, sulphate, lactate and acetate, and the results are shown in Table III.

Table III.

Percentage of strains producing 0.4 or more milligrammes of nitrite nitrogen per litre on different ammonium salts.

Carbonate	Phosphate	Sulphate	Lactate	Acetate
0	35.5	16.1	45.1	3.2

From this it is seen that of the salts tested the lactate was the most suitable though phosphate also gave good results. Among the species that have been worked upon in greater detail the following four, P 15, P 30, L 24 and Z 20, have been found readily to form nitrite when urea is the sole source of nitrogen in the culture medium. A similar result in the case of asparagin was obtained by Cutler and Mukerji⁽¹⁾.

The actual amounts of nitrite formed on phosphate, sulphate and lactate are given for certain representative strains in Table IV.

Table IV.

Nitrite nitrogen in milligrammes per litre produced by various strains on ammonium salts.

Strain	Phosphate (days)			Sulphate (days)			Lactate (days)	
	3	5	7	3	5	7	5	7
D 28	0	0	0	0	0	0	0.1	0.8
J 10	0.4	0.8	0.4	0.8	0.4	0.2	0	0
N 18	0.25	0.4	0.8	0.1	0	0	0	0
P 15	0.05	0.4	0.4	0	0	0	0	0
P 30	0.4	0.8	0.8	0.8	0.2	0.1	0.1	0.4
S 37	0	0	0	0	0	0	0	0.8
S 40	0	0	0	0	0	0	0.05	0.8
X 44	0	0	0.1	0.05	0.8	0.1	0	0
Z 20	0.2	0.4	0.4	0.05	0.8	0.1	0.05	0.8

Disappearance of nitrite.

It will be seen from Table IV that the amount of nitrite in the cultures fluctuated from time to time; thus, while it sometimes increased steadily, as in the case of N 18 on phosphate, in other cases there was a sudden falling off in amount, as is seen with P 30 on sulphate. It was decided therefore to test whether the disappearance was due to the absorption of nitrite by the bacteria, or to its reduction to ammonia. Fourteen strains were inoculated into a mineral salt solution containing 1.6 mgm. per litre of nitrogen as sodium nitrite. The results are given in Table V.

Table V.

Disappearance of nitrite in the presence of various bacterial species.

Mgm. of nitrite nitrogen per litre
(days)

Strain	0	3	5	7
J 7	1.6	1.6	0.1	0
J 9	1.6	0	0	0
J 10	1.6	0.3	0.2	0
K 16	1.6	0.4	0.4	0.2
L 24	1.6	1.6	1.6	0
N 16	1.6	0.3	0	0
N 18	1.6	1.5	0.6	0
P 30	1.6	0.8	0.8	0.05
S 31	1.6	0.4	0.4	0
X 14	1.6	0	0	0
X 44	1.6	1.6	1.2	0
Y 12	1.6	0	0	0
Z 13	1.6	0	0	0
Z 20	1.6	0	0	0

At the end of the experiment the solutions were tested for ammonia by the Nessler reaction, and only one strain, L 24, had produced ammonia. These results are similar to those already recorded for soil bacteria by

Cutler and Mukerji(1). Although the possibility that nitrate may be formed cannot be disregarded, there is evidence to show that this did not occur in the experiments in question. It will also be noticed from Table IV that in no case did the nitrite disappear when derived from ammonium lactate. As already mentioned there is reason to believe that this salt is the one from which nitrite is most readily produced, and it is possible that in the case of the other salts the nitrogen present as nitrite is more readily available to the bacteria than when present as ammonia. In the case of the strains from soil investigated by Cutler and Mukerji(1) the same thing was found during the first 9 days on ammonium lactate though afterwards the nitrite disappeared in some cases.

In order to discover if there was any relationship between the numbers of bacteria and the amount of nitrite found, a series of experiments were set up and the bacterial numbers were counted and the nitrite estimated daily. For this purpose four species of bacteria were selected. The results of these experiments are given as a contingency table (Table VI), where the initial growth period, that is the time from the inoculation to the first maximum, is contrasted with the later period where the bacterial numbers are fluctuating.

Table VI.

Correlation of bacterial numbers with nitrite production for species L24, P15, P30, Z20; bacterial numbers given first (a + sign signifies an increase, a - sign a decrease).

	++	+-	-+	--
Growth period	68	15	—	—
Later period	38	57	60	75

For all species during the initial period nitrite formation and increase in numbers are closely correlated; but in the later period this does not occur. It would appear that when the cultures have reached maturity the numbers of bacteria and the amounts of nitrite bear little relationship one to another. A certain amount of experimental evidence has been obtained tending to show that the C/N ratio has a decided effect in conditioning the disappearance of nitrite. This fact will undoubtedly have a bearing on the contingency table figures for the later period of growth. In a further paper it is proposed to give the experimental evidence and consider this problem in detail.

A further possibility with regard to the disappearance of nitrite arises in some cases. The strains already referred to in Tables IV, V and VI do not produce acid in the course of growth, but where species are used which give rise to acid conditions in the presence of sucrose, this may

account for the disappearance of nitrite during the later stages of growth. To test this point an experiment was carried out in which a strongly nitrifying species was inoculated into a mineral salt solution containing 0.1 per cent. sucrose at a pH of 7.2. After 5 days' growth, when the pH value was reduced to 4.8, the nitrite which had previously been formed had disappeared. The culture was then sterilised to kill the bacteria and 0.7 mgm. per litre of sodium nitrite was added. The nitrite was not immediately diminished by the acid conditions, but after 48 hours' standing it had completely disappeared. Therefore in work of this kind it must be borne in mind that conditions may arise in the cultures leading to the disappearance of nitrite without the agency of bacteria; at the same time the disappearance of nitrite when acid is formed in the culture is by no means consistent since during this work many cases have been recorded when the pH value was below 5.0 but the nitrite remained.

SUMMARY.

1. One hundred and four species of bacteria which produce small quantities of nitrite from ammonium sulphate have been isolated from filters receiving waste water from a beet sugar factory, and these bacteria do not differ in their behaviour on carbohydrates from non-nitrifying bacteria from the same source.

2. Ammonium lactate is the salt of ammonia which is most readily oxidised.

3. In the majority of cases nitrite can also be utilised by these bacteria in the course of growth.

4. There is a positive correlation between increase in bacterial numbers and the percentage nitrite in a culture during the initial growth period.

5. Nitrite may disappear slowly from solutions at a pH of 4.8 when the bacteria have been killed by autoclaving; but this is not invariably the case.

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(Received August 31st, 1932.)

[FROM THE BIOCHEMICAL JOURNAL, VOL. XXVII, No. 1, pp. 240-244, 1933]

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XXXVI. THE DESIGN OF EXPERIMENTAL PERCOLATING FILTERS.

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(Received January 5th, 1933.)

IN the course of an investigation of methods of purification of effluents from beet sugar factories, which has been in progress at the Rothamsted Experimental Station during the past five years, the oxidation of solutions of carbohydrates by the process of biological filtration on percolating filters has been systematically studied. The different kinds of small laboratory percolating filters constructed specially for the experiments may be of value to other investigators in similar experimental work on the purification of sewage and various industrial waste waters. An account is therefore given in the following pages of the different filters and the circumstances in which they might be advantageously employed.

Drainpipes of earthenware or cement are obtainable in a variety of sizes. They have been found useful as containers for filtering medium in preliminary work when comparisons were desired of the effect of changing the grade of size or type of medium or the nature of the solution to be filtered. Dawson, in experiments at Rothamsted with aqueous extracts of sugar beet and of mangolds (not published) used a filter in which the medium was held in a cylinder of iron wire gauze; samples of liquid at different levels of the filter were withdrawn through small glass funnels inserted through the gauze. Dawson's experiments showed that most of the carbohydrate in solution was oxidised in the upper half of the filter. Chick [1905] made use of filters built up from glass cylindrical sections in order to study the process of nitrification in sewage. Glass funnels were arranged at various depths of the filters so that samples could be taken of the solutions undergoing filtration. These experiments led Chick to conclude that the process of nitrification is a rapid biological action which takes place in two stages, *viz.* oxidation of ammonia to nitrite and oxidation of nitrite to nitrate.

Filters built in sections separated by air spaces. It is sometimes of interest to study the progress of purification of a solution during the process of biological filtration, and for this purpose filters built in sections possess the advantage that samples of the liquid leaving each section can readily be obtained. The division of a percolating filter into a number of separate sections appears to have been introduced in 1898 by Scott-Moncrieff [1909] in order to produce a well-oxidised effluent from the strong sewage of the Caterham Barracks. This investigator used a large scale installation of four filters, each 11 ft. by 9.5 ft. and 5 ft. deep. The clinker filtering medium was arranged on seven perforated trays separated from one another by air spaces. After the sewage had passed through two septic tanks the liquor was treated in the sectional filter at a rate of 31 g.y.d.¹

¹ Gallons of liquid filtered per cubic yard of filtering material per day.

and a well nitrated effluent was obtained. In general it was found that the upper half of the complete filter removed more organic matter than the lower half, while the latter produced the greater quantity of oxidised nitrogen. Barritt [1931], who first made use of separate sections of earthenware pipes in order to study the rate of oxidation of sucrose solutions, found that most of the carbohydrate was oxidised in the upper half of the filter. Similar results were reported by Jenkins [1931] in a study of the oxidation in sectional percolating filters of solutions containing sucrose and ammonium chloride.

For certain purposes the method of splitting up a single filter into separate sections divided by air spaces suffers from the disadvantage that the results are not strictly comparable with those obtained with non-sectional filters for the following reasons: (1) separation of the sections does not permit the upward movement of organisms which is possible in the non-sectional type of filter, (2) the air spaces between the sections may affect the amount of air passing through the filters and may alter the distribution of liquid in the filtering medium. For example, the sectional filter previously used by the author [1931] consisted of six separate cylindrical glass parts, each 6" in diameter and 9" deep, with a funnel-shaped bottom supporting the medium. The liquid, which dropped on to a section, collected in the funnel and fell on to the centre of the surface of the next lower section, and then spread through the medium. Uniform distribution of the liquid over the top surface of each section was not, therefore, obtained. Thus, the percentage purifications of 0.1 % solutions of sucrose filtered through approximately the same depth of medium and at the same rate of flow in (a) a non-sectional filter, (b) three sections of a sectional filter, were 95-100 % and 66 % respectively.

Sectional filter equivalent to a single filter. A new type of filter was accordingly designed and has been operated for 2 years. This filter is comparable with a non-sectional filter and yet samples of liquid at different depths may be collected by simple manipulation. The filter is illustrated in Fig. 1 and consists of six units of octagonal cross section. The sides of the octagon are of wood and of standard size and shape (Figs. 2 a and 2 b) and the top and bottom edges are bevelled at an angle of 60° to the horizontal. The eight sides of each unit are held together in position by two 1" bands of iron, shrunk on and screwed down to each side (Fig. 2 c). The medium is supported in the section by means of a rustless steel tray made from Hadfield's C.R.I. steel. The tray, perforated and shaped as shown in Fig. 2 d, is placed inside the section and the flaps are screwed to the sides so that the tray is just flush with the bottom of the section. Each section is supported in a frame (Fig. 1) by two separate wooden pegs which are pushed through holes in the frame into sockets in blocks of wood screwed on to the sides of the octagon. Spare holes are made in the frame at suitable distances so that the sections can be lowered if necessary. The sections are filled with medium up to the level of the inside bevelling. When the sections are assembled, medium is in contact with both sides of the steel plates, and, if the holes in the plate are made large enough, particles of medium may project through from one section to the next.

Experiments on filtration are carried out with the apparatus in the position shown in Fig. 1. If samples are required from all sections, the final effluent is first sampled. The last section is then lowered and supported by the pegs in the spare holes and the effluent from the fifth section is then collected. A similar procedure is followed until the effluent from every section has been sampled.

Filters constructed entirely of glass. In experiments on the effect of adding phosphates to solutions of carbohydrate undergoing treatment in percolating

filters it is essential to exclude from the apparatus any material from which the liquid or organisms in the filter might extract phosphorus. Even resistant forms of phosphorus, such as are likely to be present in clinker and other media frequently employed, may become slowly available to bacteria and fungi. There

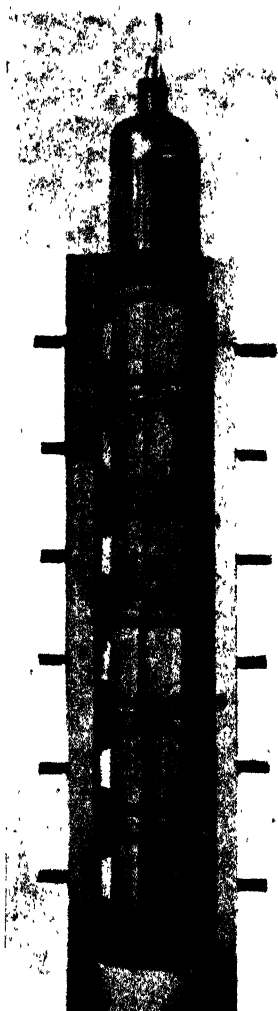


Fig. 1. Wooden percolating filter.

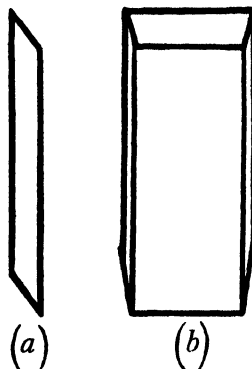


Fig. 2 a. End view of side of octagon;
b. Front view of side of octagon.



Fig. 2 c.

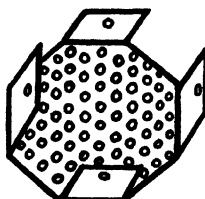


Fig. 2 d. Perforated steel filter plate.

are several non-phosphatic media obtainable, *e.g.* glass beads, which are not readily available in suitable sizes, and cullet or waste sheet glass, which is, however, difficult to break down and grade. On the suggestion of Mr E. H. Richards graded glass from broken bottles was tried in several experiments, since it is obtainable as an article of commerce. This medium was contained in

cylindrical lamp-glasses. A perforated aluminium plate was fastened to the bottom of each cylinder by means of a mixture of hot bitumen, pitch and a little tallow, and was secured in this position by a strip of aluminium which partly covered the bottom of the cylinder and partly overlapped the plate. The strip of aluminium was similar to the metallic covers used for fastening down the lids of preserved meat bottles. Any number of sections could be joined together by means of bands of rubber cut from motor car inner tubes. Each section was kept in position in a frame by a metal clip (Fig. 3 *a*). The last section rested in a glass funnel supported in a retort ring. This ring could be moved up and down

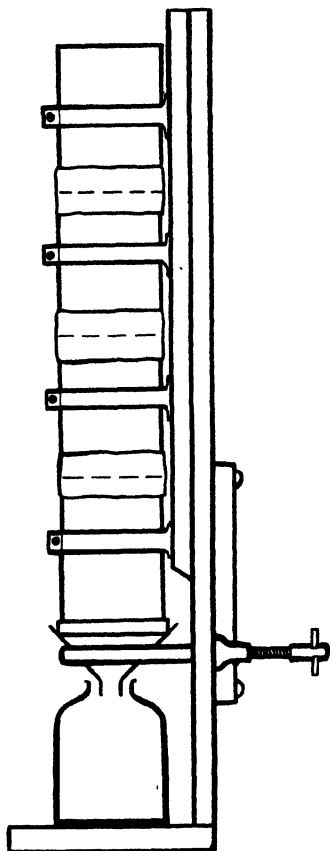


Fig. 3 *a*. Glass sectional filter.

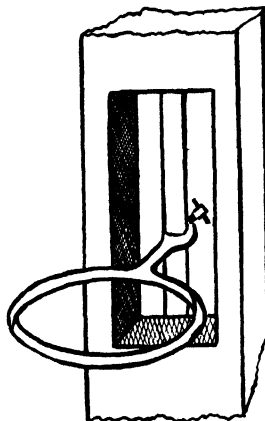


Fig. 3 *b*. Rod behind stand to support ring.

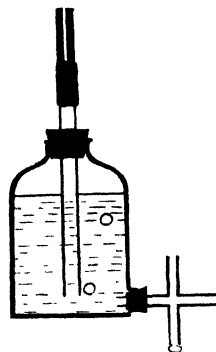


Fig. 3 *c*. Constant dripping apparatus.

a length of piping screwed on to the back of the stand (Fig. 3 *a* and *b*) so that the last section could be lowered and the effluents from any of the sections could be sampled.

The glass medium from broken bottles packed badly and filters which contained it choked after being supplied for only a short time with solutions of carbohydrate and nitrogenous compounds. At the suggestion of Dr A. Parker, the broken glass was replaced by short pieces of glass tubing. Tubes of 1 cm. bore with walls of 1 mm. thickness were cut into lengths varying from 1.5 to

2 cm. With this kind of medium the filters have proved very satisfactory. Owing to the large surface and air space there is very little tendency for the filters to choke, while dead film is not permitted to accumulate in the filter, but is rapidly washed out with the effluent.

In the various experiments, a modified form of Mariotte's bottle has been used (Fig. 3 c) for supplying liquid at a constant rate. The hydrostatic head in this apparatus is controllable by the frictional resistance offered to the passage of air through a length of thermometer capillary tubing. The four-way outlet permits of easy cleaning out of bacterial growths in the tubes.

Filters constructed entirely of glass have been used successfully for studies on the effect of filtering solutions of sucrose containing different amounts of phosphate, in order to determine the quantity of phosphorus required by a biological filter in decomposing a definite amount of sucrose. As glass medium does not interfere with the methods commonly employed for the analysis of nitrogen, phosphorus and potassium, it is possible to recover the whole of these elements contained in the film of a percolating filter. The results of experiments in which use has been made of filters constructed entirely of glass, will be published in due course.

It is a pleasure to acknowledge the assistance of Mr E. H. Richards and Mr D. M. T. Morland in the construction of the filters described in this paper. The apparatus was constructed for experiments carried out at Rothamsted Experimental Station as part of the programme of the Water Pollution Research Board, of the Department of Scientific and Industrial Research and the paper is published by permission of the Department.

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THE NITRIFICATION PROCESS IN SOILS AND BIOLOGICAL FILTERS

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(From the Department of General Microbiology,
Rothamsted Experimental Station.)

(With Plate XIV.)

CONTENTS.

	PAGE
Introduction	165
Historical review	166
Experimental:	
I. The occurrence of nitrifying organisms in a sectional biological filter	170
(a) Growth in mineral solutions	170
(b) Growth on silica gel plates	171
II. Thermal death-point of the nitrifying organisms	171
III. Nitrification in soils	172
IV. Nitrification in solutions in the presence of organic matter	173
V. Influence of reaction (pH) on nitrification	175
VI. Nature of the inhibitive action of organic matter on nitrification	176
VII. Influence of organic matter on the growth of nitrifying bacteria	178
VIII. Conclusions	180
IX. Summary	181
References	182

INTRODUCTION.

IN a recent paper on the biological filtration of dilute sucrose solutions the writer (1931) recorded the occurrence of the oxidation of ammonium lactate by means of a culture of bacteria resulting in the simultaneous formation of carbon dioxide and nitrous acid. Though nitrification in a biological filter increases with decrease in soluble organic matter, appreciable amounts of nitrite were recorded in a sectional filter (*loc. cit.*) in regions where the oxidation of soluble organic matter was not complete. It was also noticed that samples of the effluent from the upper sections containing the largest amounts of organic matter, but not showing the presence of nitrite, invariably developed nitrification on incubation, thus indicating the presence of the nitrifying organisms in all sections of the filter. It was then suggested that nitrification probably played a part in the oxidation of organic matter by supplying a hydrogen acceptor

additional to the oxygen of the dissolved air. This theory is supported by consideration of the losses of nitrogen known to occur during the fermentation of organic nitrogen compounds under partially aerobic conditions (Adeney and Letts, 1908; Russell and Richards, 1917).

The occurrence of nitrification in the presence of organic matter has long been a matter of common experience and stands in marked contrast to the conclusions of the classical researches of Winogradsky on the nitrifying bacteria. According to him these organisms require the absence of organic matter and the presence of carbonates, whereas in soil, in filter beds and in river water they may nitrify in the absence of carbonates and in the presence of organic matter. The possibility of a symbiosis existing between the nitrifying organisms and the common heterotrophic organisms has been hinted at by several workers but without any definite data to support it. Though the behaviour of nitrifying organisms in mixed culture has been the starting-point in most investigations of nitrification, it has always been with the object of their ultimate isolation rather than the obtaining of a satisfactory interpretation of the nitrifying process under natural conditions.

In his recent review of the present position of our knowledge of the nitrification process, Winogradsky (1931) deplores the fact that no progress has been made during the last 40 years. A further review of the literature from this standpoint is necessary to reveal in what direction progress is possible and how far it may be achieved without recourse to pure cultures dependent upon a too specialised technique.

HISTORICAL REVIEW.

Pasteur's prediction of the biological nature of nitrification was first fulfilled in 1877 in two independent investigations by Storer in America, and Schloesing and Muntz in France. Schloesing and Muntz (1878) showed that nitrification was not a common property of oxidising organisms, and in 1879 they showed that the process was favoured by a moderate degree of alkalinity and small amounts of organic matter. They also found that all their nitrifying cultures contained one common type of organism in the form of an ovoid micrococcus.

Warington (1878-9) found that nitrification of soil cultures was increased by addition of tartrates which on oxidation yielded a "salifiable base" and also by the addition of chalk which was found to be essential for complete oxidation of the ammonia. His most remarkable, but hitherto neglected, observation was that of a similar stimulating effect of the addition of small amounts (0.005 per cent.) of sugar which

yielded no salifiable base on oxidation. In the absence of both chalk and organic matter no nitrification was possible. In 1885 he showed the existence of an optimum alkalinity. In 1888 and 1891 he recorded the failure of the gelatine plate method of isolation, though his nitrifying cultures contained a particular type of organism common to all, viz. a micrococcus which formed zoogloea.

Heraeus (1886), in contrast to the findings of Schloesing and Muntz, and of Warington, found nitrification to be a common property of several well-known bacteria including common pathogenic types. Though these results have not been definitely confirmed, other later workers have obtained similar results. Frankland accounted for these results by the reduction of nitrates occurring in the water used in making the culture solutions, whilst Winogradsky suspected the absorption of nitrous acid from the air. Celli and Zucco (1886) recorded results similar to those of Heraeus.

Munro (1886) was the first to question the necessity of organic carbon to the nitrifying organisms. He found that nitrification could occur to some extent in filtered river water.

Frankland, P. F. and G. C. (1890), definitely proved that organic carbon is not essential to the organism. Since all gelatine plate cultures refused to nitrify, they resorted to isolation of the organism by repeated dilution cultures in mineral salt solution and were ultimately successful in isolating an organism which nitrified ammonia readily and refused to grow on gelatine and peptone media. This organism was a micrococcus or short bacillus similar to that described by Schloesing and Muntz, and Warington. In view of this it is remarkable that fuller recognition of the Franklands' priority should not have been accorded by subsequent workers.

One month after the appearance of the Franklands' paper, Winogradsky (1890) published his account of the isolation of the nitrifying organism. His method was to take "clots" of the zoogloea and magnesium carbonate from enrichment cultures, wash them in sterile water and test for purity by growth on gelatine plates. Those inoculations which showed no growth were removed and re-inoculated into ammonium sulphate solutions. In this way cultures of nitrifying organisms were obtained which would not grow on nutrient gelatine. In 1891 Winogradsky devised his silica gel plate method of isolation, the novelty and ingenuity of which immediately captivated and has ever since dominated the minds of most soil bacteriologists. The organism thus isolated resembled the ovoid micrococcus forming zoogloea as described by Schloesing and Muntz, Warington, and the Franklands. Winogradsky, however, was the

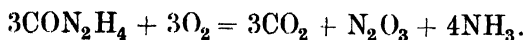
first to describe its metabolic peculiarity of being able to assimilate carbon dioxide in a manner similar to that of his other autotrophic bacteria which derive their energy from the oxidation of sulphur and iron. Not only did he find organic matter unnecessary to this organism but positively harmful. In conjunction with Omeliansky (1899), he found that glucose, peptone and bouillon, at concentrations of 0.2 per cent. and higher, completely inhibited nitrification, whereas glycerine, asparagin, acetates, butyrates and urea only delayed the process. Realising the difficulties of the original silica gel plate for the isolation and cultivation of this organism, in 1925 he published a new method of preparing the plate by adding the mineral salts and ammonium sulphate to the surface of the solid gel followed by a final surface layer of chalk. Inoculations of the organisms are then made on the layer of chalk, and their growth is indicated by the appearance of clear colonies against the white background of undissolved chalk.

Jordan and Richards (1890) found the organism in tap water and in natural waters throughout the state of Massachusetts. On filter beds they found nitrification inversely proportional to bacterial numbers and gelatine plate cultures refused to nitrify. They repeated and confirmed Frankland's dilution method for the isolation of the organism.

Since 1890 many workers have investigated this subject. The autotrophic nature and bouillon sterility of the organisms rigidly described by Winogradsky have been confirmed by Godlewski (1896), Omeliansky (1899), Boullanger and Massol (1903), Löhnis (1904), Joshi (1915), Meyerhof (1916), Bonazzi (1919), Gibbs (1919), Rubentschik (1929), Engel (1930) and Nelson (1931). Calmette (1905) discussed the work of Boullanger and Massol in relation to nitrification in biological filtration. Although excess of ammonia retarded the growth of *Nitrobacter* in pure culture it did not impair its oxidising power. In an established filter the symbiosis between the *Nitrosomonas* and *Nitrobacter* organisms enables large amounts of ammonia to be oxidised direct to nitrates without the appearance of more than traces of nitrites. Similarly he suggested that the presence of organic matter whilst retarding the growth of *Nitrosomonas* does not prevent the oxidation of ammonia by organisms already established. In this way the oxidation of albuminoids to ammonia, of ammonia to nitrite and nitrite to nitrate may occur simultaneously in the same portion of the filter.

Many more workers, however, have obtained results not conforming to the strict requirements of autotrophism. Thus, Leone and Magnanini (1891) obtained the complete nitrification of gelatin; Adeney (1908), in

experiments on the oxidation of peaty matters, found that ammonia and oxygen may disappear without formation of nitrites or nitrates, but on further aeration oxidised nitrogen may be formed in amounts greater than can be accounted for either by the oxidation of ammonia or the reduction of oxygen and concludes that not only the organic nitrogen but also the combined oxygen of the peat takes part in the fermentative changes. He also records the direct oxidation of urea to nitrous acid and gives the equation in support of it:



Beddies (1899) found that growth on silica gel plates was increased by the presence of humus; Stutzer (1901) found agar plates more suitable than silica gel; Fremlin (1903, 1930) obtained the same organism from silica gel plates and broth-agar plates; Chick (1905) isolated nitrifying organisms from sewage by the silica-plate method, but when sterile on bouillon they showed feeble nitrifying powers; Muntz and Lainé (1906) found that the residues of organic decomposition were not harmful to nitrification and that ammonium humate nitrified more rapidly than the sulphate; Coleman (1908) found that addition of dextrose up to 0.2 per cent. increased nitrification in soil, but delayed or suppressed nitrification in pure cultures in sand and in solution. Though the cultures were sterile on bouillon, dextrose was decomposed. He considers that dextrose was not toxic but acted as a stimulant. Owen (1908) obtained better growth of nitrifying organisms on washed agar than on silica gel; Makrinoff (1909) found that gypsum plates were more suitable for isolation and that the presence of soil organic matter was toxic only in large quantities; Beijerinck (1914) criticised autotrophism as applied to *Nitrobacter* (the nitrate-forming organism), since he found it capable of growth on bouillon; Gowda (1924) found it impossible to obtain nitrifying bacteria that would not grow on bouillon; Sack (1925) isolated nitrifying organisms from silica plates which grew better on agar and organic media and could assimilate carbon from both carbon dioxide and sugar. These organisms also oxidised nitrites to nitrates.

A third group of workers has isolated several strains of organisms that nitrify in solution containing organic matter and refuse to grow in inorganic media. Thus, Mischustin (1926) isolated two such organisms from soil; Runov (1926) confirmed this and concluded that nitrification is a common property of many organisms; Cutler and Mukerji (1931) isolated four species of soil bacteria which nitrified ammonium salts in the presence of sugar, but also showed a stronger tendency to decompose

170 *Nitrification Process in Soils and Biological Filters*

nitrites. These observations are similar to those made by Heraeus in 1886. Quite recently Lipman and Greenberg (1932) report the isolation of nitrifying organisms capable of oxidising paraffin and of assimilating carbon from this substance.

It would appear from this review that amongst recent workers there exists considerable support for the views of those who worked prior to Winogradsky's clear-cut account of the autotrophic character of the organisms. The condemnation of all workers who record growth of nitrifying bacteria in organic media is somewhat arbitrary and has no *a priori* justification. Such workers may or may not be working with pure cultures, and this point cannot be decided by a negative characteristic which may mean nothing more than damage to the particular inoculation.

In the following experiments no attempt was made to isolate the nitrifying bacteria in a state of purity. A stock culture of nitrifying bacteria was obtained by inoculation into Omeliansky solution of nitrifying material from a biological filter. Inoculations from this stock culture were effected into sterile media by the usual bacteriological technique.

EXPERIMENTAL.

I. THE OCCURRENCE OF NITRIFYING ORGANISMS IN A SECTIONAL BIOLOGICAL FILTER.

(a) *Growth in mineral solutions.*

The sectional filter used in this experiment is described in detail by the writer elsewhere (Barritt, 1931). Inoculations of 1 c.c. of effluent from each section were made with 50 c.c. of sterile Omeliansky solution contained in 250 c.c. conical flasks. After incubation at 22° C. for 14 days the solutions were tested for nitrites colorimetrically by the Griess-Ilosvay reagents with the following results:

Table I.

Sectional culture No.	Nitrite N in parts per million produced in 14 days
1	10
2	15
3	60
4	120
5	120
6	110

Although nitrite was absent from the effluents of sections 1, 2 and 3 it appeared in the cultures in definite amounts and thus confirms the presence of nitrifying organisms in all sections of the filter.

Ashby (1904) used the amounts of nitrite produced in a given time as a measure of the nitrifying powers of soil samples.

Inoculations of 1 c.c. from culture 4 alone into six flasks containing 50 c.c. of Omeliansky solution gave the following results:

Table II.

Flask	Nitrite N in parts per million produced in 14 days
A (1 c.c.)	110
B "	100
C "	100
D "	105
E "	100
F "	110
G (2 c.c.)	190

The amounts of nitrite produced are proportional to the amount of the inoculum with a fluctuation of ± 5 per cent.

The figures in Table I may therefore be considered to be proportional to the respective numbers of nitrifying organisms in the effluents of the various sections of the filter.

(b) *Growth on silica gel plates.*

Silica gel plates were made by Winogradsky's later method (1925). In this method the nutrient salts and chalk are added to the surface of the solidified gel. Plates were inoculated from the sectional filter by means of a platinum loop. After incubation for 14 days the growth of the nitrifying organism was indicated by formation of clear spots in the white layer of chalk. In the centre of these spots colonies of the organism appeared as a raised gelatinous mass of a light brown colour. The rate of growth of the colonies varied with the particular inoculation, those from sections 4, 5 and 6 being more rapid than those from the upper sections (see Plate XIV).

It must be concluded from these experiments that nitrifying organisms occur in all sections of a biological filter and that these organisms are capable of growth under purely autotrophic conditions similar to the *Nitrosomonas* described by Winogradsky. They also live under the heterotrophic conditions of a biological filter supplied with a solution containing 0.2 per cent. sucrose and 0.05 per cent. ammonium sulphate.

II. THERMAL DEATH-POINT OF THE NITRIFYING ORGANISMS.

A series of cultures was set up in Omeliansky solutions. After 4 days, when active nitrification was indicated, the flasks were heated in a water bath for 15 min. at temperatures ranging from 45 to 70° C. It was found that after 14 days no further nitrification had occurred in the flasks

172 *Nitrification Process in Soils and Biological Filters*

heated to 58° C., but it continued vigorously in flasks heated to temperatures below 54° C. The thermal death-point of these nitrifying organisms is therefore between 54° and 58° C., which is in agreement with the results of other workers.

III. NITRIFICATION IN SOILS.

A number of soil samples from widely different sources was air-dried in the laboratory and passed through a 1 mm. sieve. Half gram samples of each soil were then put into 50 c.c. of Omeliansky solution and incubated at 25° C. The amounts of nitrite produced were determined at intervals and the results obtained are given in Table III.

Table III.

Soil used for inoculation	Amounts of nitrite N in parts per million after			
	7	14	28	56 days
1. Rothamsted Park Grass AmSO_4 + lime	6	12	40	250
2. " " " AmSO_4 alone	0	0	0*	25
3. " Broadbalk unmanured	0	1	5	300
4. " " " dunged plot	45	120	300	Trace (N_2O_5)
5. " " " AmSO_4	50	120	300	Trace (N_2O_5)
6. " Agdell	20	65	250	3 (N_2O_5)
7. Woburn	1	20	40	0 (N_2O_5)
8. Harpenden Common (sod)	Trace	1	10	Trace (N_2O_5)
9. " " (worm casts)	3	100	150	0 (N_2O_5)
10. Russian Light Podsol	0	Trace	50	300
11. Nigerian soil (pH 4.1)	0	0	0*	28
12. " " (pH 4.3)	0	0	0*	25
13. " " (pH 8.0)	5	100	300	130 (N_2O_5)

* These soils were inoculated with 1 c.c. of solution from culture 4 on this date.

These results show great differences in the nitrifying powers of different soils. Samples 4 and 5 show the highest rates of nitrification. They represent Broadbalk Plots 2 (dung) and 8 (ammonium sulphate) which have received 87 annual dressings of 129 lb. of nitrogen per acre. Sample 3 came from the Broadbalk unmanured plot. Samples 2, 11 and 12 showed no sign of nitrification after 28 days, and were therefore inoculated with nitrifying organisms from culture 4 to test for the possible presence of a substance inhibitive of nitrification. Nitrification occurred in all three cases, showing that no such substance was present. Sample 2 represents the permanent grass plot which has received ammonium sulphate for 75 years. The pH of this soil is 4.4, due to the accumulation of sulphuric acid. Sample 1 came from the portion of the same plot which had received a dressing of lime every 4 years, the pH of this soil being 6.0.

Samples 8 and 9 are interesting as showing a greater nitrifying power of soil after passage through earthworms. Two factors may account for this increased nitrifying power of worm casts, viz. (1) the removal of the organic matter by digestion by the worm, and (2) the neutralising effect of the calcareous glands of the worm and the possible addition of calcium carbonate from subsoil chalk. Samples 1 and 8, both taken from grass-land, show delayed nitrification and incomplete development. These samples are characterised by the presence of oxidisable organic matter which probably interfered with the normal course of nitrification as shown by samples 3, 4, 5 and 6.

IV. NITRIFICATION IN SOLUTIONS IN THE PRESENCE OF ORGANIC MATTER.

Nitrifying cultures were prepared from the stock culture using Omeliansky solution in which the calcium carbonate was replaced by various organic compounds. The progress of nitrification was tested at intervals. The results obtained for the various substances are given in Table IV.

Table IV.

		Nitrite N in parts per million after					
Culture solution		3	7	14	21	28	56 days
1.	Mineral salts + CaCO_3	2	50	120	270	400	400
2.	" " + NaHCO_3	0.5	5	70	200	350	0
3.	" " alone	1	15	18	10	Trace	0
4.	" " + urea 0.05 %	0.5	15	45	80	150	0
5.	" " + urea 0.1 %	0.5	4	15	45	80	250
6.	" " + glycine 0.05 %	Trace	1	10	50	120	50
7.	" " + glycine 0.1 %	Trace	—	Trace	1	5	150
8.	" " + uric acid 0.05 %	—	2	35	50	100	200
9.	" " + " " 0.1 %	—	0.5	20	50	130	300
10.	" " + lemco 0.05 %	—	Trace	15	30	45	Nil
11.	" " + " " 0.1 %	—	—	2	20	60	Nil
12.	" " + peptone 0.05 %	—	—	2	30	50	Nil
13.	" " + asparagin 0.05 %	Trace	4	20	20	60	Nil
14.	" " + amm. acetate 0.05 %	—	Trace	10	45	65	50
15.	" " + amm. lactate 0.05 %	—	1	25	40	50	Nil
16.	" " + dextrose 0.05 %	—	Trace	8	20	10	Nil
17.	" " + cellulose 0.05 %	—	Trace	2	50	30	10
18.	" " + paraffin 0.02 %	—	Trace	1	3	20	5

Formation of nitrate occurred in all these cultures.

The course of the nitrification process shows considerable variation with the different organic compounds. Culture 1 with no organic matter and excess chalk shows the most complete nitrification. The buffering effect of the chalk enabled the process to continue uninterruptedly, until all the ammonia was oxidised. In all the other cultures considerable change in pH occurred after 21 days. Ammonification of the organic compounds tended to raise the pH during the first 2 weeks and subsequent

174 *Nitrification Process in Soils and Biological Filters*

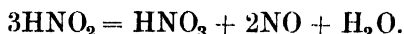
nitrification lowered the *pH* which reached values as low as 5.5 in 28 days and 4.5 in 56 days.

In every case the presence of organic matter tended to retard nitrification as compared with the presence of chalk, the effect in general increasing with the rise in concentration of the carbon and hydrogen content of the molecule. Thus, asparagin, peptone, acetate, dextrose, cellulose and paraffin delayed nitrification in that order and more than did uric acid and urea. This effect may be due to localised anaerobic conditions brought about by the oxidation of these compounds.

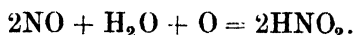
Culture 3, which contained neither chalk nor organic matter, started with an initial *pH* of 7.3 and rapidly became acid, with the result that nitrification ceased after 14 days. In the other cultures without chalk but containing organic matter nitrification proceeded much further. Organic matter appears therefore to take the place of mineral carbonates in supplying the necessary carbon dioxide for synthesis and ammonium carbonate as a temporary buffer. This property of organic matter in promoting nitrification in the absence of mineral carbonates accounts for the stimulating effect of small quantities of sugar observed by Warington and Coleman and for the observations of Fred and Graul (1916) that in acid soils organic nitrogen nitrifies more rapidly than ammonium sulphate.

When the *pH* falls to 5.5 nitrification ceases followed by disappearance of the nitrous acid, the formation of nitric acid, and a further lowering of *pH* to 4.5. This formation of nitrate before all the ammonia was nitrified was characteristic of most of the cultures especially those in which ammonification was absent, viz. dextrose, cellulose and paraffin.

As a biological process the conversion of nitrous acid to nitric acid at a *pH* of 4.5 appears improbable. It can be accounted for by purely chemical catalysis, by the reactions:



The nitric oxide in solution absorbing oxygen from the air renders the reaction continuous:



Confirmation of this reaction was obtained by acidifying two solutions of sodium nitrite, one with sulphuric acid and the other with acetic acid to *pH* of 5.0. The solution contained 50 parts of nitrite N per million, and after standing in conical flasks at 18° C. for 3 weeks the solutions gave the following results on analysis:

Acid	Parts per million	
	Nitrite N	Nitric N
Sulphuric	Nil	47
Acetic	0.5	49

The above reactions probably account for the formation of nitrates in acid soils and in the absence of chalk. They may also account for the observations of Sack (1925) and Lipman and Greenberg (1932) of nitrifying organisms capable of oxidising ammonia direct to nitrates in the presence of dextrose and paraffin respectively. They may also explain the supposed induced oxidation of sodium nitrite by air in the presence of ferrous hydroxide observed by Chakravarti and Dhar (1930) to occur only when alkali is added *after* the ferrous sulphate. The addition of the acid ferrous salt liberates free nitrous acid which would undergo oxidation before addition of the alkali. The formation of ferrous hydroxide is not therefore essential to the oxidation of the nitrite, and the amounts of nitrite oxidised will depend upon the interval of time between adding the ferrous sulphate and its neutralisation by the alkali.

V. INFLUENCE OF REACTION (*pH*) ON NITRIFICATION.

This factor was first investigated by Meyerhof (1916) and later by Meek and Lipman (1922), who found the optimum conditions for the oxidation of ammonia to be between *pH* 7·5 and 8·5. Accurate figures are not easily obtainable, since it is impossible to maintain precise conditions above *pH* 7·0 during active nitrification or below 6·5 in the presence of chalk.

In the absence of chalk it has already been shown (section IV) that the lower limit for nitrification is about *pH* 5·5. Series of Omeliansky solutions containing chalk were prepared with *pH* ranging from 6·7 to 9·2 and were inoculated with 1 c.c. of the stock culture. The amounts of nitrites formed and resulting changes in *pH* after 3 and 7 days are given in Table V.

Table V.

Influence of pH on nitrification.

Period in days	Nitrite N in parts per million													
	1		2		3		4		5		6		7	
	<i>pH</i>	<i>NO</i> ₂	<i>pH</i>	<i>NO</i> ₂	<i>pH</i>	<i>NO</i> ₂	<i>pH</i>	<i>NO</i> ₂	<i>pH</i>	<i>NO</i> ₂	<i>pH</i>	<i>NO</i> ₂	<i>pH</i>	<i>NO</i> ₂
—	6·7	1	7·3	1	7·5	1	8·0	1	8·5	1	8·8	1	9·2	1
3	6·7	3	7·1	3	7·4	3	7·9	3·5	8·5	2·0	8·8	1·5	9·2	1
7	6·7	18	7·0	18	7·1	18	7·6	18	8·4	6·0	8·7	4·0	9·2	1·5

The *pH* was determined colorimetrically using brom-thymol-blue and cresol red indicators. At *pH* 8·5 there is definite reduction in the rate of nitrification, which practically ceases at 9·2. There appears to be no significant difference in the rate of nitrification between 6·7 and 8·0.

VI. NATURE OF THE INHIBITIVE ACTION OF ORGANIC MATTER
ON NITRIFICATION.

It is unlikely that substances like peptone, asparagin and dextrose which are products of organic metabolism would be toxic to any type of bacteria. Their action in depressing nitrification is more easily explicable as being due to the growth of heterotrophic bacteria present in the cultures. Nelson (1931) claims that his pure cultures of *Nitrosomonas* were capable of nitrification in the presence of dextrose in amounts as high as 10 per cent., from which it may be concluded that dextrose is toxic only when the nitrifying culture is impure and that the toxicity is due to the metabolic products of the contaminants.

The recovery of nitrification after 14 days as seen in Table IV suggests that the toxic substance is either unstable or volatile. It was therefore decided to investigate the effect of carbon dioxide on nitrification. Godlewski (1896), Joshi (1915), Bonazzi (1921), and Gowda (1924) found that increasing the carbon dioxide in the air of the culture flasks to 50 per cent. resulted in a slight increase in the amount of nitrite formed especially in the presence of chalk. This result is rather surprising, since the increase in carbon dioxide involved a corresponding reduction in the concentration of oxygen which many workers (Löhns, Bonazzi and Berthel) have found to be an important factor in determining the rate of nitrification. Joshi accounts for the observed stimulation as being due to an increased solubility of the calcium carbonate in the culture solution. This implies that the amount of soluble carbonate was a limiting factor, which is very improbable, since ammonium carbonate is formed by interaction between ammonium sulphate and chalk, and the ratio of carbon assimilated to nitrogen oxidised is only 1/35. Further, as nitrification proceeds, the buffering action of the chalk must result in an increasing formation of soluble bicarbonate, which, being indirectly proportional to the amount of nitrite produced, would supply the needs of the organisms more than thirty times over. Some other explanation must be found for this stimulating effect of carbon dioxide observed by these workers.

In the sterilisation of the mineral salt solution interaction between the various salts occurs. Potassium carbonate is formed by interaction between chalk or magnesium carbonate and di-potassium phosphate. Ammonium carbonate is similarly formed from the ammonium sulphate during incubation, especially at the higher laboratory temperatures common in India. The formation of these alkali carbonates results in an

increase in pH which at 8.5 retards nitrification. The addition of carbon dioxide to such a culture solution would, by reducing the pH nearer to 8.0, result in increased nitrification.

By using culture solutions in which nitrification is already established and in which the possible fluctuations in pH are within the range 7.0–8.0 and therefore indifferent, the effect of carbon dioxide concentration *per se* can be more correctly determined. The addition to the cultures of carbon dioxide in the form of a prepared solution of carbonic acid, instead of the maintenance of an increased percentage of carbon dioxide in the air of the culture flasks, more nearly corresponds to the conditions of a solution in which carbon dioxide is being evolved by the fermentation of organic matter under normal atmospheric conditions.

A solution of carbonic acid was obtained from a sparklet siphon. Titration of this solution with *N*/10 soda after standing 1 hour showed it to contain 0.13 per cent. by weight of carbon dioxide.

Various amounts of this carbonic acid solution were added to culture solutions in which nitrification had already proceeded for 7 days, and the subsequent nitrite formation was determined. The results are given in Table VI.

Table VI.

Effect of carbon dioxide on nitrification.

Culture No.	Carbonic acid added gm.	Nitrite N in parts per million				
		At start	After 1 day	After 3 days	After 5 days	After 14 days
1	—	150	180	210	240	400
2	0.006	150	180	210	240	400
3	0.012	150	150	170	190	390
4	0.018	150	140	145	155	380

These results show a definite initial depression of nitrification by the addition of 0.012 gm. of carbon dioxide to 50 c.c. of culture solution, whilst the addition of 0.018 gm. of carbon dioxide stops nitrification completely for 3 days, recovery occurring after 5 days.

On the fifth day sub-cultures were made from cultures 1 and 4 by transferring 1 c.c. of the suspension into flasks containing 50 c.c. of sterile Omeliansky solution. The subsequent nitrification in these two flasks proceeded at equal rates, from which it must be concluded that the numbers of active nitrifying organisms in cultures 1 and 4 were equal. It appears therefore that although carbon dioxide suppressed nitrification in culture 4 the growth of the organisms continued unchanged. This fact rules out toxicity and suggests that lack of oxygen produced by the

178 *Nitrification Process in Soils and Biological Filters*

increased carbon dioxide tension is the more probable cause of the suppression of nitrification. The continued growth of the bacteria in culture 4 without the production of nitrites could only be possible on the supposition that some intermediate compound was formed similar to that postulated by Beesley (1914) to account for the temporary disappearance of nitrogen (ammonia plus nitrite) in the early stages of nitrification.

The depression of nitrification by the addition of 0.024 or 0.036 per cent. of carbon dioxide fully accounts for the observed effects of organic compounds on this process. The fermentation of 0.05 per cent. peptone or dextrose would result in the production of approximately this amount of carbon dioxide, and the addition of larger amounts of organic compounds by their longer period of fermentation would result in a very prolonged suppression of nitrification.

Attempts to diminish the depressing effect of organic matter by vigorous aeration were only partially successful. Increased aeration not only lowers the concentration of carbon dioxide but also lowers the concentration of ammonia which diminishes the rate of nitrification. The complete removal of carbon dioxide by inserting a tube of strong alkali within the culture flask (*vide* Winogradsky, Omeliansky, Godlewski, Bonazzi and Gowda) leaves an accumulation of free ammonia with a consequent rise in *pH* above the optimum, resulting in a depression of nitrification. This effect of the removal of carbon dioxide from the cultures led these authors to conclude erroneously that gaseous carbon dioxide was essential to nitrification.

VII. INFLUENCE OF ORGANIC MATTER ON THE GROWTH OF NITRIFYING BACTERIA.

The occurrence of nitrification in the presence of organic matter naturally raises the question of its effect on the autotrophic character of the organisms. Is the growth of the nitrifying bacteria in the presence of organic matter entirely autotrophic (*i.e.* organic synthesis from carbon dioxide)?

Unfortunately the only satisfactory measurement of growth applicable to these organisms is the production of nitrites, and this is affected by changes in the concentration of carbon dioxide and oxygen. In section IV it has already been shown that nitrification was most rapid in cultures containing chalk and free from organic matter. In order to obtain comparative measurements of the growth and nitrifying power of the organisms growing in the presence of organic matter, sub-cultures in Omeliansky

solution are necessary so as to exclude fluctuations in carbon dioxide and oxygen concentration.

For this purpose a series of nitrifying cultures was prepared containing different organic compounds. After incubation at 25° C. for 48 hours, when considerable bacterial growth had occurred, inoculations of 1 c.c. were transferred to Omeliansky solution and the rates of nitrification determined. Similar sub-cultures from the original culture into Omeliansky solution were also made 4 weeks later. The results are given in Table VII.

Table VII.

Composition of culture solution	Amounts of nitrite N in parts per million							
	Primary culture			1st sub-culture (after 48 hours)		2nd sub-culture (after 28 days)		
	2 days	7 days	28 days	4 days	21 days	4 days	10 days	21 days
Mineral salts + CaCO ₃ + Am ₂ SO ₄	Trace	55	400	Trace	350	60	125	400
Mineral salts + 0.05 % glycine	—	1	85	—	250	25	115	400
Mineral salts + 0.05 % asparagin	—	3	40	—	350	35	120	400
Mineral salts + 0.05 % peptone	—	—	50	—	380	35	100	380
Mineral salts + 0.05 % dextrose	—	—	20	—	350	4	85	350
Mineral salts + 0.05 % lactose	—	—	12	—	370	20	90	370

The first sub-cultures made after 48 hours show that the depressing effect of the organic matter on the nitrifying bacteria is not carried over into the sub-cultures except perhaps in the case of glycine. In two cases, viz. the cultures containing peptone and lactose, there appears if anything to have been a slight stimulation of the nitrifying organisms. The increase is less than 10 per cent. and according to section I above is scarcely significant.

The second sub-cultures (on the 28th day) taken from the flasks containing organic matter show a definite depression of nitrification on the 4th day especially with dextrose, but a rapid recovery appears by the 10th day, which is complete on the 21st day except in the case of dextrose and lactose.

Although the results are not conclusive regarding the occurrence of heterotrophic growth in nitrifying bacteria, they definitely show an absence of toxicity from 0.05 per cent. asparagin, peptone, dextrose and lactose.

VIII. CONCLUSIONS.

The foregoing investigations confirm the findings of Boullanger and Massol (1903), Chick (1905) and Russell and Bartow (1915) that the nitrifying bacteria in biological filters are identical with those present in soil, *i.e.* they are capable of autotrophic growth and have a low thermal death-point (56° C.). Many of the contradictory results of observations of the nitrification process, such as growth in the absence of mineral carbonates, the stimulating and inhibiting effect of organic matter and gaseous carbon dioxide, the uncertain nature of the growth on bouillon tests and the direct production of nitrates from ammonia, can be accounted for by the metabolism of heterotrophic contaminants and by changes in pH of the medium.

Gibbs (1919), Gowda (1924) and Nelson (1931) found that repeated sub-culture under autotrophic conditions did not diminish the numbers of heterotrophic bacteria whether in mineral solutions or on silica gel plates. This may be considered strong evidence of a symbiosis between the two types of organisms and would account for the numerous failures to repeat Winogradsky's work in its entirety. It should be pointed out that Winogradsky obtained his isolation by washing his nitrifying inocula (clots) in sterile water and selecting only those showing bouillon sterility. Nelson later got over the difficulty of removing contaminants by suppressing them with copper sulphate and resorting to single cell technique. Both methods are actually dependent upon chance and perseverance for success. Any nitrifying culture obtained by whatever means would, according to Winogradsky, be condemned as impure if it subsequently acquired the power of growth on bouillon.

The Franklands, before Winogradsky's first publication, obtained by selection nitrifying cultures which showed no growth on bouillon. Later generations, however, developed the property of growth on bouillon. Gibbs, Gowda and Nelson obtained similar results.

According to Winogradsky the nitrifying bacteria can grow only by producing nitrite. To this limitation he added that of toxicity of organic compounds. Pure cultures of the organism are thus characterised by a very restricted mode of existence, which may account for the lack of progress in their study to which he referred.

The question of the internal metabolism of these bacteria was not discussed by Winogradsky. The synthesis of sugar or protein implies the existence of an enzyme system similar to that occurring in the protoplasm of plants, and it would be pushing the unique to extreme limits to suppose

such a system to be incapable of katabolic processes. In this connection it may be mentioned that Beijerinck (1890), Radais (1900) and Bristol-Roach (1926) found that pure cultures of green algae though normally autotrophic were also capable of growth on albuminoids and carbohydrates.

Bonazzi (1921) suggested the possibility of carbon dioxide respiration of the autotrophic bacteria to account for nitrification in the absence of free carbon dioxide in the culture, but since free carbon dioxide is not essential to the process this is not evidence of katabolism. In mixed cultures the necessary carbon dioxide is obtainable from the normal respiration of the heterotrophic bacteria and there is strong evidence of a symbiosis between the two types of organisms. Calmette, Boullanger, and Massol suggested that the effect of organic matter was to check the growth, but not the oxidising powers, of the nitrifiers. Since autotrophic organisms derive their energy for growth from the oxidation of ammonia, a reduction in growth would imply a reduction in the rate of oxidation (nitrification). Nelson (1931) found that enrichment cultures did not become enriched with nitrifying organisms, but that the numbers of heterotrophs maintained an almost constant proportion. This suggests that either the heterotrophs lived at the expense of the nitrifiers or that some of the latter were passing into a heterotrophic condition. Beijerinck held this view of the mutability of the nitrifiers, but Winogradsky could not admit this possibility. To the writer a possible way out of this apparent impasse is the observation of heterotrophic mutants acquiring nitrifying powers and becoming autotrophic. This would give one stage of a possible life cycle, and it appears to have occurred in the cultures obtained from the second sub-cultures described in section VII above. The increase in nitrification in these autotrophic cultures is more rapid than that obtained by similar inoculation from one autotrophic culture to another.

A biological filter probably presents the conditions favourable to the occurrence of such a possible life cycle for the nitrifying organisms.

IX. SUMMARY.

1. An extensive review of the literature on nitrification shows that the workers in this subject may be divided into three groups, viz. (a) the Winogradsky or purely autotrophic group, (b) those who include growth in organic media, (c) those who exclude autotrophic growth.

2. The process of nitrification in soils and filter beds is essentially the same and the organisms concerned exhibit the same cultural characteristics, viz. autotrophic growth in purely mineral solution containing carbonates and low thermal death-point (56° C.).

182 *Nitrification Process in Soils and Biological Filters*

3. In the absence of carbonates heterotrophic organisms can supply the necessary carbon dioxide by the decomposition of organic matter, a process which accounts for nitrification in acid soils and filter beds. In the absence of a salifiable base the oxidation of ammonia is arrested by the formation of free acid and at a pH of 5.5 the nitrous acid is spontaneously oxidised to nitric acid.

4. The inhibitive action of organic matter on nitrification can be accounted for by accumulation of carbon dioxide and ammonia and deficient aeration. Removal of any of these factors results in increased nitrification.

5. Increased nitrifying power of soil after passage through earthworms is recorded and accounted for.

6. The restrictive influence of Winogradsky's ideas on autotrophism are discussed, and the possibility of nitrifying bacteria being a phase in the life cycle of heterotrophic organisms is suggested.

The investigations described in this paper were carried out at Rothamsted Experimental Station as part of the programme of the Water Pollution Research Board of the Department of Scientific and Industrial Research and are published by permission of the Department.

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184 *Nitrification Process in Soils and Biological Filters*

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EXPLANATION OF PLATE XIV.

Silica gel plates inoculated direct from a sectional filter showing development of colonies of nitrifying bacteria. The numbers of the plates correspond to the numbers of the sections of the filter. No. 4 shows the tracks of a small fresh-water crustacean (*Viguiierella viguierei*) which frequently occurs in nitrifying effluents.

(Received May 11th, 1932.)

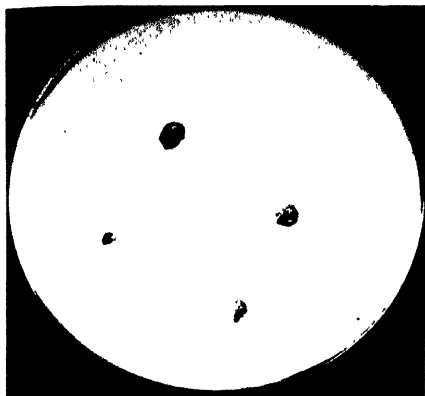


Fig. 1.

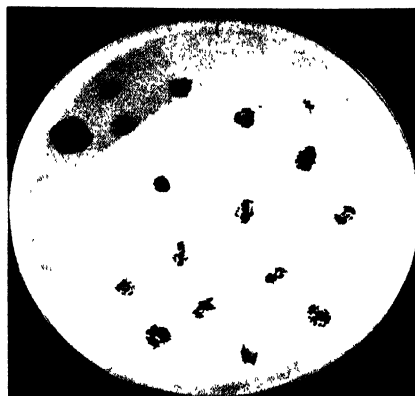


Fig. 2.

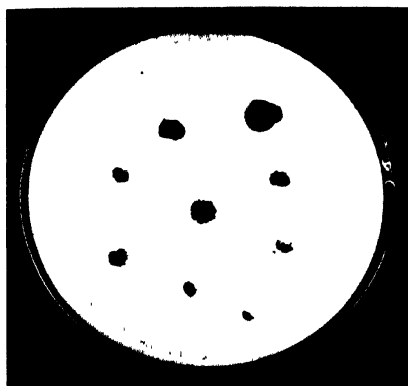


Fig. 3.

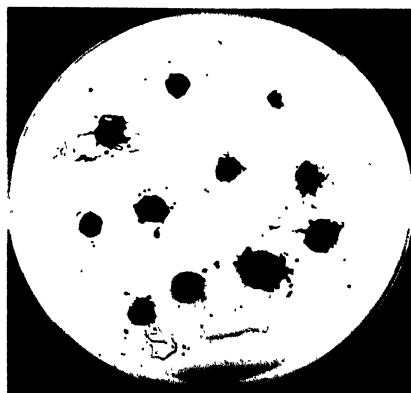


Fig. 4.

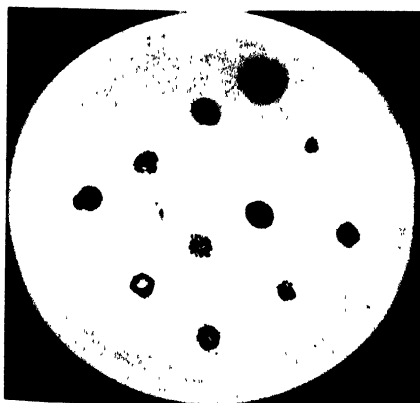


Fig. 5.

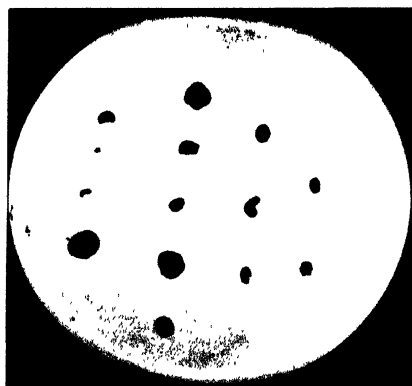


Fig. 6.

[FROM THE ANNALS OF APPLIED BIOLOGY, VOL. XX, No. 1,
pp. 146-164, FEBRUARY, 1933.]
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THE BIOLOGICAL DECOMPOSITION OF PLANT MATERIALS

PART VIII. THE AVAILABILITY OF THE NITROGEN OF FUNGAL TISSUES

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(With 2 Text-figures.)

CONTENTS.

	PAGE
I. Introduction	146
II. Scheme of work	148
III. Experimental	148
(i) Fungal tissue as a source of nitrogen for the decomposition of straw	148
(ii) Liberation of ammonia from fungal tissue by bacteria	152
(iii) Nitrification of fungal tissue in soil	153
IV. Discussion	160
V. Summary	163
References	164

I. INTRODUCTION.

IN earlier papers of this series certain chemical aspects of the decomposition of plant materials were discussed. While the assimilation of the plant constituents by micro-organisms is the most obvious feature of decomposition, attention has also been directed to the importance of the accompanying synthesis of microbial tissue. It is difficult to form any very exact estimate of the quantity of such microbial tissue synthesised during decomposition; it may vary from 5 to 20 per cent. of the original substance according to the condition and the availability of the material and the type of organism present. As has been pointed out, the supply of available nitrogen to meet the synthetic or structural needs of the micro-organisms is, in nature, not infrequently a limiting factor. The nitrogen is immobilised by the organisms as protein and other nitrogenous compounds in the microbial tissue. This is, of course, the case in farmyard manure and composts. If such materials are subsequently applied to

the soil, the manurial value will depend chiefly on the amount and the rate of liberation of this nitrogen in an inorganic and plant-available form. The organic matter of the soil itself must be, in part, composed of such microbial residues, the availability or stability of which is of prime importance in determining soil fertility. Many investigators have stated that microbial tissue is very resistant to decomposition, and that the nitrogen of fungal and bacterial cells is, accordingly, relatively unavailable. If it were really so, soil microbiological activities would have long since reached a very low level, and the soil would have a high content of organic nitrogen. The only logical deduction is that microbial nitrogen must be available. The point at issue is therefore whether it is liberated rapidly or only very slowly.

It is not proposed to attempt a complete review of the literature dealing with the decomposition of microbial tissue and the availability of its nitrogen, since such has very recently been given by Jensen (4).

Heck (3), in 1929, carried out a detailed study of the decomposition of fungal tissue in the soil. He concluded that such material decomposes readily in moist soils, since from 40 to 60 per cent. of the carbon is liberated as carbon dioxide in 26 days, and from 30 to 40 per cent. of the nitrogen during the same period. Furthermore, he claimed that the nitrogen of fungal tissue is nitrified as rapidly, or perhaps even more rapidly, than that of other organic materials of similar nitrogen content. His results indicate an extremely close correlation between the nitrogen nitrified and the C/N ratio of the tissues employed, a fact which was, perhaps, insufficiently stressed by him. Those tissues with a narrow C/N ratio underwent rapid nitrification, while if the ratio was wide nitrification in the same period was slow. It was unfortunate that in this work Heck largely employed tissues of higher fungi, not involved in general soil processes. While it is probable that such species as *Polyporus* or *Fomes* are similar in composition to the common soil organisms, it is by no means certain. The only soil organisms employed by this worker were *Aspergillus oryzae*, *Trichoderma lignorum*, and *Coprinus radians*. It must be admitted that these particular samples did not differ in behaviour from the others, but, nevertheless, it seemed desirable to extend the investigation to other soil organisms and to pay particular attention to the influence of the C/N ratio of the tissue, as distinct from the availability of the nitrogenous constituents. The major part of the work to be described, therefore, is a study of the nitrification of numerous samples of fungal tissue and the comparison of these with different controls built up to the same C/N ratio.

An important communication by Jensen (4) dealing with the de-

composition of the cells of soil micro-organisms recently appeared. He was particularly concerned with the nitrification of farmyard manure in soil, and therefore with the availability of microbial tissue. He found nitrification of fungal tissue to be quite rapid up to a point, but not complete, and postulated the existence of some part of the nitrogen in a highly resistant form. Heck⁽³⁾ had found a direct correlation between the C/N ratio of the tissue and the degree of nitrification in equal time, but although Jensen considered this as a possibility he was unable in his results to find any clear relationship between the two. The experiments to be described bear directly on this point of variance and support the conclusions arrived at by Heck⁽³⁾.

II. SCHEME OF WORK.

Investigations of the availability of the nitrogen of fungal tissue were carried out along three distinct lines.

(i) The suitability of fungal nitrogen as a source of nitrogen for the decomposition of straw was examined, and the extent of decomposition compared with that produced in the presence of various simpler nitrogenous compounds. In most cases, a mixed soil flora was employed to decompose the straw and fungal tissue mixture; but a few experiments were made in which the decomposition was effected by an organism in pure culture.

(ii) The rate of liberation of ammonia from fungal tissue by pure cultures of reputedly active ammonifying bacteria was studied.

(iii) The nitrification in soil of a number of samples of fungus tissue was compared with that of controls of equal C/N ratio, which consisted of cellulose, straw and glucose, each with added inorganic nitrogen, in an attempt to disentangle the two factors affecting nitrification, namely, the effect of the C/N ratio of the material, and the availability of the nitrogenous constituents.

III. EXPERIMENTAL.

(i) *Fungal tissue as a source of nitrogen for the decomposition of straw.*

The fungus tissue employed was obtained by growth in large pans on a glucose-ammonium nitrate medium in the presence of calcium carbonate. In two cases the quantity of the nitrogen source was increased fivefold in order to obtain microbial tissue of high nitrogen content and narrow C/N ratio. The inoculum was a generous suspension of spores washed off on agar slant in a bottle. The pans were left at room temperature for 10 days, and the mycelial pad then killed by brief autoclaving. After

thorough washing to remove calcium carbonate the mycelium was dried gently in a vacuum oven at 60° C. and subsequently ground to a fine powder and sieved till of approximately uniform particle size. The following tissues were employed in this section of the investigation:

	N content %	C content %
*1. <i>Aspergillus versicolor</i>	7.57	41.9
*2. Mixed tissue (fungi and bacteria)	7.18	42.4
3. <i>A. fumigatus</i>	3.40	43.4
4. <i>A. terreus</i>	3.22	39.1
5. <i>A. niger</i>	2.59	41.0

* Grown on high nitrogen medium.

Equal quantities of oat straw (0.79 per cent. N) were placed in small bottles holding about 40 gm. and a source of nitrogen was added at the rate of 0.8 gm. per 100 gm. dry straw. The calculated quantities of the simple nitrogenous sources were added in solution; while the appropriate amounts of the fungal tissues containing an identical quantity of nitrogen were, on the other hand, thoroughly mixed with and dispersed

Table I.

Decomposition of oat straw supplied with different sources of nitrogen.
48 days—30° C.

37.4 gm. dry straw (containing 0.29 gm. N) and additional nitrogenous material containing 0.3 gm. N = 0.59 gm. total N.

No.	Additional nitrogenous source	Weight of N source added gm.	Residue gm.	% decom- position of mixture	% organic N in residue*	Weight of organic N gm.	N not immobi- lised gm.	Added N retained in organic form gm.	N retained per 100 gm. straw
1	None	—	18.98	49.3	1.69	0.32	+ 0.03	—	—
2	None	—	19.45	48.0	1.75	0.34	+ 0.05	—	—
3	Amm. carbonate	1.00	14.41	62.5	2.96	0.43	0.16	0.14	0.37
4	Amm. carbonate	1.00	14.34	62.7	2.93	0.42	0.17	0.13	0.35
5	Sodium nitrate	1.82	15.71	60.0	2.83	0.44	0.15	0.15	0.40
6	Urea	0.60	14.56	61.7	3.20	0.47	0.12	0.18	0.48
7	Amm. nitrate	0.80	14.41	62.3	2.84	0.41	0.18	0.12	0.32
8	Peptone	1.83	15.31	61.0	2.80	0.43	0.16	0.14	0.37
9	Sodium nitrite	1.64	16.52	57.7	2.94	0.49	0.10	0.20	0.53
10	<i>A. versicolor</i>	3.97	17.25	58.3	3.13	0.54	0.05	0.25	0.67
11	<i>A. versicolor</i>	3.97	16.62	59.3	3.20	0.53	0.06	0.24	0.64
12	Mixed tissue	4.18	15.32	63.2	3.85	0.59	0.00	0.30	0.80
13	Mixed tissue	4.18	15.30	63.2	3.64	0.56	0.03	0.27	0.72
14	<i>A. fumigatus</i>	8.82	18.75	59.6	3.00	0.56	0.03	0.27	0.72
15	<i>A. fumigatus</i>	8.82	19.30	58.4	3.07	0.59	0.00	0.30	0.80
16	<i>A. terreus</i>	9.31	18.00	61.5	3.34	0.60	+ 0.01	0.30	0.80
17	<i>A. terreus</i>	9.31	18.45	60.5	3.21	0.59	0.00	0.30	0.80
18	<i>A. niger</i>	11.60	23.07	53.0	2.66	0.60	+ 0.01	0.30	0.80
19	<i>A. niger</i>	11.60	22.60	53.9	2.63	0.59	0.00	0.30	0.80

* Total N—inorganic N (i.e. $\text{NH}_3\text{—N} + \text{NO}_3\text{—N}$ where present).

150 *The Biological Decomposition of Plant Materials*

throughout the straw in the dry state. Water was added to give a final moisture content of 80 per cent. on the basis of total organic matter present. No special inoculum was added, since it has been found that straw commonly carries a sufficiently diverse flora for decomposition. The bottles were loosely plugged with cotton-wool and incubated in a horizontal position at 30° C., being turned and stirred frequently during the first few days to ensure complete and even wetting. At the end of 48 days, the contents of the bottles were analysed for ammoniacal and total nitrogen (nitrate also where necessary) and for loss of organic matter. The results are summarised in Table I.

The particular sample of oat straw employed had an unusually high nitrogen content (0.79 per cent.) and without an additional supply of nitrogen lost 49 per cent. organic matter in decomposition. In the presence of ammonium carbonate, however, the nitrogen factor was 0.36, that is, 100 gm. straw in decomposing would immobilise or convert to the organic form an additional 0.36 gm. N and at the same time suffer a loss of over 62 per cent. of the organic matter. Other simple sources of nitrogen appeared to be almost equally suitable, with the exception of nitrite, which had, as might have been expected, a slightly depressing effect on the amount of straw decomposed. When the additional nitrogen required was supplied in the form of fungus tissue, decomposition in all cases was normal. The rotted product was rather darker in colour than usually is the case when inorganic N is supplied, and in addition had an odour as of manure, in contrast to the slightly sweet odour of the decompositions in the presence of inorganic nitrogenous salts. It is a little difficult fairly to compare the figures for percentage decomposition in the presence of fungus tissue with those just mentioned, owing to the presence of additional carbonaceous material in the added tissue. This is very considerable in those cases in which the nitrogen content of the tissue is low. Despite this limitation, however, it may easily be seen that the extent of decomposition is of the same order whether nitrogen is supplied in an inorganic form or in the form of fungus tissue. The data are insufficient to justify a claim that the latter source may be preferable, though the figures obtained in bottles 12, 13, which were supplied with a sample of mixed fungal and bacterial tissue, might indicate this. It is interesting to compare these two bottles with Nos. 10, 11 supplied with *Aspergillus versicolor* tissue. They are quantitatively comparable since the weight of added tissue was almost the same in both cases. The mixed tissue is clearly more suitable as a nitrogen source, and decomposition is 4.4 per cent. greater. Bottles 16, 17 and 14, 15 are also approxi-

mately comparable. In this case, although rather more carbonaceous material was added, the *A. terreus* tissue is shown to be slightly more suitable and decomposable than that of *A. fumigatus*. It is doubtful whether this difference is really significant.

Though in all these experiments with added fungal tissue there is present an excess of nitrogen over the determined requirements of the straw in decomposition, little is lost during the period of the experiment except in the case of the *A. versicolor* tissue. The calculated nitrogen factors in Nos. 10-19 are not really valid inasmuch as the quantity of carbonaceous material present at the beginning of the experiment is greater in these cases owing to the presence of the added mould mycelium. It is, no doubt, this additional carbonaceous material which causes the retention of a higher amount of nitrogen.

In a few experiments, the decomposition was carried in pure culture instead of by the agency of a mixed flora. The procedure was similar to that described earlier, except that all constituents were sterilised. The inoculum in each case was a suspension of the spores of the desired organism obtained by washing off a colony grown on agar. At the close of the experiments plantings were made from the decomposed straw to check the purity of the organism responsible for the rotting. Table II gives the results of these experiments.

Table II.

Decomposition of oat straw by pure cultures of fungi. 48 days—30° C.

37.4 gm. dry straw (contains 0.29 gm. N) and additional nitrogenous material containing 0.3 gm. N.

No.	Organism	Additional nitrogenous source	Weight of N source added gm.	Residue gm.	% decom- position of mixture	% organic N in residue	Weight of organic N gm.	N not immobilised gm.	Added N	
									retained in organic form gm.	N retained per 100 gm. straw
1	<i>Trichoderma</i> sp.	Ammon. carbonate	1.00	28.19	26.6	1.55	0.44	0.15	0.15	0.40
2	"	Mixed tissue	4.18	29.89	28.1	1.63	0.49	0.10	0.20	0.53
3	"	<i>A. niger</i>	11.60	36.80	25.0	1.52	0.56	0.03	0.27	0.72
4	<i>A. niger</i>	Ammon. carbonate	1.00	33.21	13.6	1.40	0.46	0.13	0.17	0.45
5	"	<i>A. niger</i>	11.60	38.34	21.8	1.36	0.52	0.07	0.23	0.61
6	<i>A. versicolor</i>	Ammon. carbonate	1.00	27.86	27.5	1.59	0.44	0.15	0.15	0.40
7	"	Mixed tissue	4.18	28.64	31.1	1.84	0.53	0.06	0.24	0.64
8	<i>A. terreus</i>	Ammon. carbonate	1.00	28.60	25.5	1.71	0.49	0.10	0.20	0.53
9	"	Mixed tissue	4.18	26.10	37.1	1.93	0.51	0.08	0.22	0.59
10	"	<i>A. niger</i>	11.60	37.60	23.3	1.56	0.59	—	0.30	0.80

Owing to the different quantities of carbonaceous material added, it is again difficult to make valid comparisons. In each case, however, there was a definitely higher percentage loss of organic matter in the presence of microbial nitrogen than in the presence of ammonium

152 *The Biological Decomposition of Plant Materials*

carbonate. Since the number of organisms and samples of fungus tissue tested is not very large, it is perhaps unwise to draw any general conclusion. Reviewing, however, these results together with those presented in Table I, the indication is clearly that the nitrogenous constituents of fungal mycelium are far from being resistant, and indeed seem readily available to micro-organisms whether alone or in a mixed flora.

(ii) *Liberation of ammonia from fungal tissue by bacteria.*

It was thought that a more direct test of the availability of fungal nitrogen might be given by determining the ammonification effected by known ammonifying bacteria. Two samples of fungal tissue only were employed, one with a high and the other with a low nitrogen content:

	% N	% C	C/N
(i) <i>A. versicolor</i> tissue	7.57	41.9	5.5
(ii) <i>A. niger</i> tissue	2.59	41.0	15.8

The following bacteria were selected on the basis of reports in the literature as to their activity in ammonification: *B. subtilis* (two strains), *Mycoderma* (from silage), *Proteus mirabilis*, *P. vulgaris*, *B. mesentericus*, *Sarcina lutea*, and *B. fluorescens liquefaciens*. In addition an enrichment culture was obtained from soil by repeated transfers in peptone broth.

The experiments were carried out in sand culture, 100 gm. sand being placed in each of a number of 250 c.c. Erlenmeyer flasks. To each was added 1 gm. of fungus tissue, which was then thoroughly distributed throughout the sand by shaking. After sterilisation each was inoculated with 2.5 c.c. of a 3-day-old culture of the respective bacteria in 1 per cent. peptone broth. In addition 20 c.c. of sterile water containing 1.0 gm. KH_2PO_4 per litre was added to each. The flasks were plugged with cotton-wool and incubated at 30° C. At the end of 1, 2 and 4 weeks samples were taken for analysis. Liberated ammonia was washed out of the sand by leaching on a filter paper with 5 per cent. KCl and determined subsequently by distillation with MgO. Controls were similarly treated in the absence of fungal tissue. Table III summarises the results obtained, due correction having been made for ammonia from the peptone in the inoculum. The two samples of tissue behaved very differently, and only traces of ammonia were liberated from that with a low nitrogen content, and a wide C/N ratio. However, even the *A. versicolor* tissue with a nitrogen content of over 7 per cent. did not exhibit rapid ammonification with any of the organisms employed, 19 per cent. being the maximum found in any case. It is believed that some ammonia was

lost by volatilisation, since nitrogen balances made by determining the organic nitrogen remaining in the sand were a little short. For this reason it is clear that such results do not give a very reliable index of availability of the nitrogen, but are included because of their bearing on the question of the influence of C/N ratio on availability.

Table III.

Ammonification of fungus tissue in sand culture.

1 gm. of tissue taken (*A. versicolor* = 75.7 mg. N, *A. niger* = 25.9 mg. N).

		7 days		14 days		28 days	
		mg. NH ₃ -N	% total N	mg. NH ₃ -N	% total N	mg. NH ₃ -N	% total N
<i>A. versicolor</i> tissue, C/N = 5.5							
No.	Ammonifying organism						
1	Mixed soil ammonifiers	4.8	6.3	7.6	10.0	11.9	15.7
2	<i>B. subtilis</i> (i)	6.3	8.3	5.9	7.7	1.9	2.6
3	<i>B. subtilis</i> (ii)	5.3	7.0	8.3	11.1	13.8	18.3
4	<i>Mycoderma</i> (silage)	5.5	7.3	4.7	6.3	6.4	8.4
5	<i>Proteus mirabilis</i>	4.5	6.0	4.7	6.3	12.4	16.4
6	<i>P. vulgaris</i>	6.3	8.3	5.5	7.3	3.5	4.6
7	<i>B. mesentericus</i>	6.1	8.1	4.7	6.3	14.5	19.2
8	<i>Sarcina lutea</i>	5.7	7.5	5.2	6.9	2.2	2.9
9	<i>B. fluorescens liquefaciens</i>	7.5	9.9	8.7	11.5	8.4	11.1
<i>A. niger</i> tissue, C/N = 15.8							
1	Mixed soil ammonifiers	—	—	—	—	0.4	1.5
2	<i>B. subtilis</i> (i)	—	—	0.6	2.6	0.6	2.3
3	<i>B. subtilis</i> (ii)	—	—	0.9	3.5	1.0	3.9
4	<i>Mycoderma</i> (silage)	0.7	2.7	0.7	2.7	0.6	2.3
5	<i>Proteus mirabilis</i>	—	—	—	—	1.1	4.1
6	<i>P. vulgaris</i>	0.1	0.4	0.9	3.5	1.1	4.1
7	<i>B. mesentericus</i>	0.2	0.8	—	—	1.1	4.1
8	<i>Sarcina lutea</i>	—	—	0.1	0.4	2.5	9.7
9	<i>B. fluorescens liquefaciens</i>	—	—	—	—	—	—

(iii) *Nitrification of fungal tissue in soil.*

Since the ammonification experiments with pure cultures were not successful in throwing much light on the availability of the nitrogen of fungal tissue, nitrification experiments were carried out in soil under conditions likely to be more normal for microbial development. Two main series of experiments were made, one in soil of low organic matter (a surface soil from a hill-side) and the other in a soil rich in organic matter and of high initial nitrate content (from a glasshouse). It was considered that the latter would be a soil of higher microbiological activity than the former, and therefore likely to provide the best conditions for the decomposition of the fungal tissue. The experiments were

154 *The Biological Decomposition of Plant Materials*

in each case carried out in a mixture of equal weights of sand and soil, so that aeration might be satisfactory and the even distribution of the added tissue more readily effected. A weighed quantity of tissue was added to 100 gm. sand and mixed carefully. On the addition of the necessary amount of air-dry and sieved soil and after thorough shaking, good distribution was achieved. The fungal tissue had previously been killed by brief autoclaving, dried and finely ground till capable of passing through a 40-mesh sieve. It was thought advisable to employ the tissue in this state so that distribution might be satisfactory. The consensus of opinion of other workers is that tissue, fresh, or air dried, but not killed, is more available than when heat killed. This was stated independently by Heck (3), by Barthel and Bengtsson (1) and by Engel (2). This last worker, in the case of *Azotobacter chroococcum*, compared the rate of nitrification of material prepared in three different ways. Cells dried at 105° C. gave a liberation of 33 per cent. of the total N, living cells scraped off Petri plates and incorporated in the soil gave 44 per cent., and cells actually developed and grown in the soil gave 57 per cent. in equal time. The moisture content was, as far as possible, kept constant throughout; initially 40 c.c. was added to the mixture. Samples were taken for analysis at appropriate periods. Free ammonia and nitrate were the only determinations made.

The following samples of tissue were employed in series I with hill-side soil.

	% C	% N	C/N ratio
1. <i>A. versicolor</i>	41.9	7.57	5.53
2. Mixed organisms	41.0	4.32	9.5
3. <i>A. terreus</i>	39.3	3.22	12.20
4. <i>A. fumigatus</i>	43.4	3.40	12.76
5. <i>A. niger</i>	41.0	2.59	15.8

For purposes of comparison a number of parallel experiments were set up with artificial mixtures of the same carbon/nitrogen ratios as the tissues employed. One group consisted of cellulose + nitrogen (in the form of ammonium sulphate) and the other of straw + nitrogen (in the form of ammonium sulphate). In setting these up due allowance was made for the organic nitrogen already present in the straw (0.79 per cent.). The carbon contents of the cellulose and straw were respectively 44.4 and 45.0 per cent. Both were finely divided and distributed in the sand-soil mixture as carefully as possible and treated precisely in the same fashion as in the fungal tissue experiments. The results of both are given together in Table IV. Since the nitrate liberated from the soil alone was very small in amount, the ammonia and nitrate found must be due to the added fungal material, and it is convenient for purposes of comparison

Table IV.

Nitrification of fungal tissue in hill-side soil.

- (1) *A. versicolor*. C/N=5.53: C=41.9, N=7.57. 1 gm. taken + 100 gm. soil + 100 gm. sand. Expressed on 1 gm. material (75.7 mg. N).

Period in days	Mould tissue			Cellulose + (NH ₄) ₂ SO ₄			Straw + (NH ₄) ₂ SO ₄		
	NH ₃ -N	NO ₃ -N	% N liberated	NH ₃ -N	NO ₃ -N	% N liberated	NH ₃ -N	NO ₃ -N	% N liberated
48	0.3	45.4	60.4	0.5	56.6	75.5	0.3	34.6	46.0
90	0.3	52.1	69.1	0.4	62.3	82.8	0.2	33.0	43.8
120	0.3	46.4	61.7	1.0	57.4	77.0	0.5	35.0	46.9
180	0.6	61.1	81.4	0.5	58.2	77.5	0.3	33.7	45.0

- (2) Mixed fungi and bacteria. C/N=9.5: C=41.0, N=4.32. 1.3 gm. taken and 100 gm. soil and 100 gm. sand. Expressed on 1 gm. material (43.2 mg. N).

Period in days	Mould tissue			Cellulose + (NH ₄) ₂ SO ₄			Straw + (NH ₄) ₂ SO ₄		
	NH ₃ -N	NO ₃ -N	% N liberated	NH ₃ -N	NO ₃ -N	% N liberated	NH ₃ -N	NO ₃ -N	% N liberated
48	0.2	16.9	39.6	0.3	32.1	75.0	0.1	20.1	46.7
90	0.4	22.7	53.5	0.2	30.9	72.0	0.2	21.3	49.7
120	0.3	21.0	49.3	0.4	33.8	79.1	0.4	22.2	52.3
180	0.6	26.0	61.5	0.3	37.8	88.2	0.4	22.2	52.3

- (3) *A. terreus*. C/N=12.20: C=39.3, N=3.22. 1.5 gm. taken + 100 gm. soil + 100 gm. sand. Expressed on 1 gm. material (32.2 mg. N).

Period in days	Mould tissue			Cellulose + (NH ₄) ₂ SO ₄			Straw + (NH ₄) ₂ SO ₄		
	NH ₃ -N	NO ₃ -N	% N liberated	NH ₃ -N	NO ₃ -N	% N liberated	NH ₃ -N	NO ₃ -N	% N liberated
48	0.0	10.6	32.9	0.2	27.2	85.0	0.3	15.3	48.5
90	0.2	11.9	37.6	0.3	23.0	72.4	0.1	11.8	37.0
120	—	—	—	0.2	22.7	71.1	0.3	17.9	56.5
180	0.2	16.3	51.2	0.3	23.5	74.0	0.1	19.4	60.5

- (4) *A. fumigatus*. C/N=12.76: C=43.4, N=3.40. 1.5 gm. taken + 100 gm. soil + 100 gm. sand. Expressed on 1 gm. material (34.0 mg. N).

Period in days	Mould tissue			Cellulose + (NH ₄) ₂ SO ₄			Straw + (NH ₄) ₂ SO ₄		
	NH ₃ -N	NO ₃ -N	% N liberated	NH ₃ -N	NO ₃ -N	% N liberated	NH ₃ -N	NO ₃ -N	% N liberated
48	0.2	12.6	37.6	0.4	21.1	63.2	0.2	15.0	44.6
90	0.2	16.0	47.6	0.3	20.5	61.1	0.1	15.1	44.6
120	—	—	—	0.2	20.6	61.1	0.6	17.1	52.0
180	0.3	18.0	53.8	0.4	21.5	64.5	0.3	19.8	59.0

- (5) *A. niger*. C/N=15.8: C=41.0, N=2.59. 2 gm. taken + 100 gm. soil + 100 gm. sand. Expressed on 1 gm. material (25.9 mg. N).

Period in days	Mould tissue			Cellulose + (NH ₄) ₂ SO ₄			Straw + (NH ₄) ₂ SO ₄		
	NH ₃ -N	NO ₃ -N	% N liberated	NH ₃ -N	NO ₃ -N	% N liberated	NH ₃ -N	NO ₃ -N	% N liberated
48	0.1	5.4	21.2	0.3	12.1	47.9	0.2	10.0	39.4
90	0.2	8.3	32.8	0.1	12.8	49.7	0.3	12.5	49.4
120	0.0	9.4	36.2	0.3	16.7	65.6	0.2	15.8	61.7
180	0.1	10.8	42.0	0.2	15.7	61.4	0.2	15.0	58.7

- (6) Soil. Control. 100 gm. soil + 100 gm. sand. Expressed on 100 gm. soil.

Day	NH ₃ -N	NO ₃ -N
—	Nil	3.1
48	Nil	3.5
90	Nil	3.3
120	Nil	4.0
180	Nil	4.4

to express this as a percentage of the total organic nitrogen added. It will be seen from Fig. 1 that there is a very clear correlation between the C/N ratio of the fungal tissue, and the nitrogen liberated as ammonia and nitrate (this liberation is termed by Jensen and others "mineralisation"). Nitrification of tissue of a narrow C/N ratio (*e.g.* 5.5) was rapid and extensive. 60 per cent. was thus liberated in 48 days and over 80 per cent. in 6 months. At the other end of the scale, a tissue with a much wider ratio, 15.8, was nitrified far less completely in the same period, only 21 per cent. being freed in 48 days, and 42 per cent. in 6 months. On comparing this with the artificially constructed controls

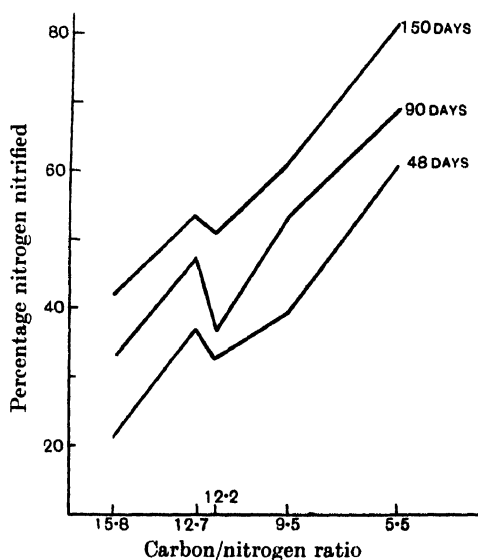


Fig. 1. Summary table of nitrification of fungus tissue in hill-side soil.

of straw and cellulose + N, it seems that nitrification of the fungal tissue is more extensive than that of these mixtures when the C/N ratio is narrow and less so when it is wide. In all cases more nitrogen is liberated from the cellulose controls than from those containing straw. This at first may appear difficult of explanation, and the converse might have been expected since the effective C/N ratio of the straw is undoubtedly narrower than that of cellulose of the same theoretical value, owing to the presence in the former of unavailable carbon in the form of lignin. However, it was observed that the cellulose decomposition was far from complete, and even at the end of the 6 months of the experiment, cellulose fibres were still clearly visible in the soil. This soil was apparently

not biologically very active, and did not carry the necessary flora for the ready and rapid decomposition of all the cellulosic material present. Samples 3 and 4 which have similar nitrogen contents and C/N ratios close together show interesting differences throughout the whole period of the experiment. The *A. terreus* tissue, though with a slightly wider ratio, nitrifies more readily than the *A. fumigatus* tissue. Such minor irregularities as this are to be expected and are explicable on the basis of a different proportion of the various carbonaceous constituents.

The following samples of tissue were employed in series II with glasshouse soil.

	% C	% N	C/N ratio
1. <i>A. ochraceous</i>	48.9	2.83	17.3
2. <i>A. flavipes</i>	48.3	3.04	15.9
3. <i>Pen. chrysogenum</i>	45.4	5.39	11.9
4. <i>A. sydowi</i>	39.8	4.73	8.4
5. <i>A. fischeri</i>	43.8	5.40	8.1
6. <i>A. citrosporius</i>	40.7	5.41	7.5
7. <i>A. oryzae</i>	42.1	6.15	6.8

The soil employed for this series was rich both in organic matter and nitrogen, and contained a considerable quantity of nitrate. Analyses gave the following figures: C = 2.56 per cent., N = 0.29 per cent., C/N ratio = 8.8. In addition to the nitrification experiments on the fungal samples, which were carried out precisely as described in the preceding section, a number of parallel experiments were made in which there were present artificial mixtures of the same C/N ratios as the tissues. These consisted of cellulose + nitrogen (in the form of ammonium phosphate), straw + nitrogen, and glucose + nitrogen. The results of all these are given together in Table V. Since the soil initially contained a considerable quantity of free nitrate, it is not feasible to calculate the nitrate found as a percentage of the original nitrogen added, and accordingly no very accurate figure can be given throughout for the percentage of nitrogen nitrified. Instead each sample must be examined individually and compared with the artificially constructed controls. Considering these first, perhaps, it will be seen that there was little difference in the liberation of inorganic N in any case between the glucose + N, and the cellulose + N series. Glucose is, of course, more readily available, but such was the biological activity of this soil that the cellulose appeared to be utilised to the same extent. Incidentally, it may be noted that in the cellulose + N series, the actual nitrification process was slackened for some reason which is not understood, with the result that considerable amounts of ammonia accumulated even over as long a period as 6 months both with narrow and wide C/N

Table V.

*Nitrification of fungal tissue and mixtures of equal
C/N ratio in glasshouse soil.*

- (1) *A. ochraceous*. C/N=17.3: C=48.9, N=2.83. 2 gm. taken + 100 gm. soil + 100 gm. sand.
Expressed on 1 gm. material (28.3 mg. fungal N) + 21.3 mg. soil nitrate N.

Period in days	Mould tissue		Glucose + amm. phos.		Cellulose + amm. phos.		Straw + amm. phos.	
	NH ₃ -N	NO ₃ -N	NH ₃ -N	NO ₃ -N	NH ₃ -N	NO ₃ -N	NH ₃ -N	NO ₃ -N
30	0.6	19.5	14.5	10.3	9.4	18.1	0.7	26.8
60	1.1	24.6	5.7	16.3	3.8	14.4	1.0	28.9
90	0.7	33.4	5.0	17.8	5.4	11.9	0.6	27.1
180	0.5	26.3	4.7	19.1	3.4	19.2	0.8	30.5

- (2) *A. flavipes*. C/N=15.9: C=48.3, N=3.04. 2 gm. taken + 100 gm. soil + 100 gm. sand.
Expressed on 1 gm. material (30.4 mg. N) + 21.3 mg. soil nitrate N.

Period in days	Mould tissue		Glucose + amm. phos.		Cellulose + amm. phos.		Straw + amm. phos.	
	NH ₃ -N	NO ₃ -N	NH ₃ -N	NO ₃ -N	NH ₃ -N	NO ₃ -N	NH ₃ -N	NO ₃ -N
30	0.9	17.6	1.6	22.4	12.8	14.2	1.9	25.5
60	0.7	28.0	0.8	20.1	7.2	15.5	0.5	27.9
90	1.2	42.8	0.1	22.6	5.9	22.6	0.4	30.6
180	0.9	43.5	0.5	27.2	3.7	19.7	0.2	32.4

- (3) *P. chrysogenum*. C/N=11.9: C=45.4, N=5.39. 1.1 gm. taken + 100 gm. soil + 100 gm. sand.
Expressed on 1 gm. material (53.9 mg. N) + 38.6 mg. soil nitrate N.

Period in days	Mould tissue		Glucose + amm. phos.		Cellulose + amm. phos.		Straw + amm. phos.	
	NH ₃ -N	NO ₃ -N	NH ₃ -N	NO ₃ -N	NH ₃ -N	NO ₃ -N	NH ₃ -N	NO ₃ -N
30	3.5	31.4	0.7	23.3	12.5	21.4	2.9	39.5
60	1.3	48.8	0.6	26.2	8.7	18.8	0.9	34.6
90	1.0	42.6	0.2	28.5	10.5	31.7	1.1	40.1
180	1.3	51.4	0.6	35.5	7.2	29.6	2.5	42.4

- (4) *A. sydowi*. C/N=8.4: C=39.8, N=4.73. 1.3 gm. taken + 100 gm. soil + 100 gm. sand.
Expressed on 1 gm. material (47.3 mg. N) + 32.7 mg. soil nitrate N.

Period in days	Mould tissue		Glucose + amm. phos.		Cellulose + amm. phos.		Straw + amm. phos.	
	NH ₃ -N	NO ₃ -N	NH ₃ -N	NO ₃ -N	NH ₃ -N	NO ₃ -N	NH ₃ -N	NO ₃ -N
30	5.1	45.3	1.0	36.3	24.8	41.8	2.7	59.3
60	2.2	59.2	1.0	42.9	14.2	35.6	1.4	59.5
90	0.9	55.6	0.2	57.4	13.0	41.6	1.3	62.7
180	2.4	52.3	0.6	58.4	13.8	38.2	1.6	56.6

- (5) *A. fischeri*. C/N=8.1: C=43.8, N=5.4. 1.1 gm. taken + 100 gm. soil + 100 gm. sand.
Expressed on 1 gm. material (54 mg. N) + 38.7 mg. soil nitrate N.

Period in days	Mould tissue		Glucose + amm. phos.		Cellulose + amm. phos.		Straw + amm. phos.	
	NH ₃ -N	NO ₃ -N	NH ₃ -N	NO ₃ -N	NH ₃ -N	NO ₃ -N	NH ₃ -N	NO ₃ -N
30	2.0	52.8	1.1	35.6	26.8	43.0	1.6	58.2
60	2.1	69.8	1.7	47.0	12.0	40.5	1.5	58.0
90	2.0	66.2	0.4	57.3	13.2	44.6	0.8	65.0
180	0.8	78.3	0.6	66.6	12.4	46.4	0.5	65.1

Table V (contd.).

(6) *A. citrosporus*. C/N=7.5: C=40.7, N=5.41. 1.1 gm. taken + 100 gm. soil + 100 gm. sand. Expressed on 1 gm. material (54.1 mg. N) + 38.8 mg. soil nitrate N.

Period in days	Mould tissue		Glucose + amm. phos.		Cellulose + amm. phos.		Straw + amm. phos.	
	NH ₃ —N	NO ₃ —N	NH ₃ —N	NO ₃ —N	NH ₃ —N	NO ₃ —N	NH ₃ —N	NO ₃ —N
30	1.0	65.4	1.2	44.4	28.0	44.2	1.3	76.0
60	1.3	67.5	1.6	50.8	18.4	41.4	1.8	68.5
90	2.4	61.6	5.0	57.7	15.7	54.6	1.6	65.6
180	0.6	67.0	1.6	64.2	19.5	47.3	0.7	68.4

(7) *A. oryzae*. C/N=6.8: C=42.1, N=6.15. 1 gm. taken + 100 gm. soil + 100 gm. sand. Expressed on 1 gm. material (61.5 mg. N) + 42.6 mg. soil nitrate N.

Period in days	Mould tissue		Glucose + amm. phos.		Cellulose + amm. phos.		Straw + amm. phos.	
	NH ₃ —N	NO ₃ —N	NH ₃ —N	NO ₃ —N	NH ₃ —N	NO ₃ —N	NH ₃ —N	NO ₃ —N
30	1.7	68.7	1.5	44.6	25.7	45.5	21.0	60.7
60	1.8	80.5	1.9	62.8	19.4	52.0	14.6	59.0
90	4.5	55.9	1.3	72.3	18.8	55.2	0.8	84.6
180	1.0	88.3	1.7	68.3	9.3	68.0	4.7	58.6

(8) Soil control. C/N=8.8: C=2.56, N=0.29. 100 gm. soil + 100 gm. sand. Expressed on 100 gm. soil.

Period in days	NH ₃ —N	NO ₃ —N
—	0.2	42.6
30	0.1	42.3
90	0.3	46.7
180	0.4	48.8

ratios. In no other series was this phenomenon observed. Rather more nitrate was liberated from the straw + N series than from either the glucose or cellulose + N series when the C/N ratio was wide, but the differences were small when it was narrower than 9. This was as anticipated, since the actual C/N ratio is somewhat closer than the theoretical owing to the presence and distribution of the lignin. Comparing with these the fungal tissue over the whole period of 6 months, it is seen from Fig. 2 that while there is a definite correlation between C/N ratio, or nitrogen content, and the nitrogen nitrified, this is far from being as regular as in the other series, particularly in those samples with a ratio less than 9. This is especially evident in samples 4, 5 and 6 which are very similar in composition. Samples 4 and 5, with approximately the same C/N ratios but different contents of nitrogen, nitrify to a distinctly different degree, sample 5 being much more available. The latter is also more available than sample 6, which has identically the same nitrogen content as sample 5 and an even narrower ratio. These differences are no doubt due to the varying availabilities of the tissue which will be discussed further later. With a wide ratio (17.3), more nitrogen was liberated from

the fungal material than in the glucose or cellulose + N series, but less than in the straw series. As the ratio gets narrower, however, the fungal nitrogen is freed to an extent greater than in any of the comparative series. This was especially noticeable in that sample with the narrow ratio of 6.8. Although, for the reasons mentioned earlier, it is not possible to give accurate figures for the percentage nitrogen nitrified, some approximation can be attempted. Nitrification appears to increase from about 20 to 75 per cent. as the C/N ratio is narrowed from 17 to 7,

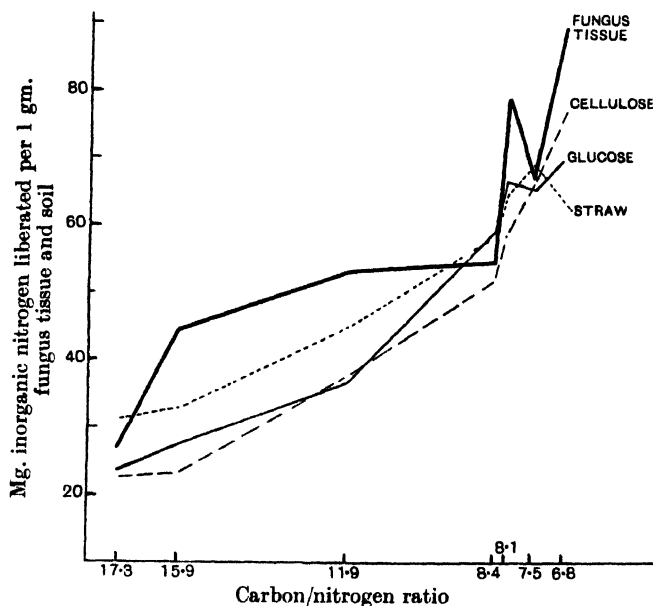


Fig. 2. Summary table of nitrification of fungus tissue and mixtures of equal C/N ratio in glasshouse soil (6 months).

and clear evidence is given for a correlation between the C/N ratio and the extent of nitrification.

IV. DISCUSSION.

Studies on the influence of the C/N ratio on decomposition and nitrification involve a consideration of several factors. The C/N ratio, though an apparently simple expression, is apt to be misleading. Decomposition depends on the C/N ratio directly, only in the unusual case of all the carbon and all the nitrogen being readily available. This, however, is in practice an infrequent occurrence, and the actual C/N ratio is at variance with the apparent figure. If a portion of the carbon

is relatively unavailable the true ratio may be considerably narrower. This is usually the case with plant materials, since the presence and distribution of the lignin reduces appreciably the available carbon. On the other hand, if a portion of the nitrogen is unavailable, the effective C/N ratio may be much wider than the apparent figure. This would be the case in such materials as leather or hair, the protein of which is not easily degraded by soil organisms. Accordingly, if an examination is to be made of the availability of the nitrogen of a given material by comparison with the nitrogen nitrified from identical experiments with the same C/N ratio, the relative availabilities of the carbonaceous constituents have also to be taken into account lest misleading results be obtained owing to the fact that the true and effective C/N ratio differs from the absolute figures upon which the control experiments were based. This is particularly the case when working with a material such as fungal tissue. Very little is known as to the chemistry and practically nothing as to the availabilities of the various individual constituents. The major part of the nitrogen has been shown to be present as soluble protein, and it is probable that such protein differs little from ordinary proteins in availability. In addition, fungal tissue is known to give 10–15 per cent. of an alkali-resistant residue, containing nitrogen, and usually described as fungal "chitin." This chitin has been shown to yield amino-glucose on acid hydrolysis. Its nitrogen content, however, varies usually between 3 and 4 per cent., according to the method of preparation, and this will account for only 33–45 per cent. of the whole residue in terms of amino-glucose. Several workers have suggested that fungal chitin would be very resistant to the attack of micro-organisms, but Jensen⁽⁴⁾ has recently proved conclusively that it is readily available. He obtained a liberation of 63·5 per cent. of its nitrogen as nitrate in 4 months. Since, therefore, it would seem that both the types of nitrogenous constituents known to be present are likely to be available, the rate of mineralisation of fungal nitrogen probably depends more on the amount and kind of energy material present. In other words, the availability and rate of decomposition of the carbohydrate constituents will determine the quantity of nitrogen liberated in the inorganic condition. Precise information as to the nature of the polysaccharides of fungi is lacking. The literature contains numerous references to such materials under many names, "Mould starch," "mycodextrins," "para-isodextrin," "spore starch," etc., but neither the constitution nor the availability has ever been determined. The fat and lipid content of fungi varies very considerably, and in some cases amounts to as much as

20 per cent. The distribution of such material might profoundly influence the rapidity of attack on the other constituents, though experiments on one sample of tissue which had undergone extraction with alcohol and saponification with alcoholic potash, did not lend much support to such a view.

The first experiments herein recorded on the availability of fungal nitrogen, and the later ones on its nitrification in the soil, do not indicate any unusual features in the decomposition of this type of material. Certainly they do not substantiate the claims made by Löhnis⁽⁵⁾ and others that fungal tissue is very resistant. Rather do they confirm the opinion of Heck⁽³⁾ and Jensen⁽⁴⁾ that the nitrogen is, at least in part, readily available to micro-organisms. Very strong support is afforded to the conclusions of Heck⁽³⁾ that the rate of nitrification depends on the quantity of energy material available, and approximately expressed by the C/N ratio. This correlation is not absolute, and appreciable differences in behaviour were observed in samples of very similar C/N ratio. It seems that Jensen⁽⁴⁾ overlooked this correlation owing to the fact that, with one exception, the samples of microbial tissue employed by him for nitrogen studies had C/N ratios lying between 8.4–12.7. This range is narrow and centred round the point of stability of the soil employed. Even so, a close examination of his results does give an indication of such a relationship though hardly an absolute proof. This is best seen in the experiments carried out by him in sand medium. Of ten samples taken five had a C/N ratio falling between 8.4 and 9.3 with an average of 8.9. The average percentage of nitrogen liberated as ammonia from this group of samples in 90 days was 63.5. Four of the remaining samples had ratios lying between 10.2 and 12.7 with an average of 11.7. From these there was liberated as ammonia only 45.4 per cent. of the nitrogen, a figure significantly lower as would be expected from a group with a wider ratio.

The various controls of equal theoretical C/N ratio employed in this work yielded results which have an important bearing on Jensen's further claim, that a portion of the nitrogen of fungal material persists in the soil as an almost unnitrifiable residue. His statement was based on the fact that the liberation of nitrogen beyond a certain point is slow. He found that little more was freed in 120 days than in the first 60 days. The experiments described in this paper were all continued for a period of 6 months. The highest percentage liberation of nitrogen in that period was 81.4 from a tissue of initial C/N ratio of 5.5. This was actually higher than the recovery from any of the artificial controls to which the nitrogen

was originally supplied as ammonia. Furthermore, in the majority of cases, more nitrogen was mineralised from the fungal tissue than from its corresponding controls. This would indicate therefore that the existence of a resistant residue is somewhat doubtful. It would seem that the ammonification and nitrification processes come practically to a standstill, not because of the unavailability of the remaining material, but because the soil population has reached a position of biological equilibrium. For most soils this condition is attained with a C/N ratio between 10 and 12 and an absence of readily available carbohydrate material. If the initial ratio be narrower, and nitrogen be present in excess of the microbial requirements in decomposition, nitrification will be more rapid than carbon loss and the organic C/N ratio accordingly widened. If the initial ratio is too wide, nitrification will be slight until by the loss of carbon the ratio has been narrowed. The evidence for the existence of a resistant residue is inconclusive, since it may be explained on the basis of the attainment of an equilibrium or of a state in which change is very slow. The fact that the unnitrified portion of the nitrogen varies in amount according to the original C/N ratio supports this thesis.

It is difficult to see why complete nitrification should be expected or, indeed, could take place in such a short space of time. The decompositions which result in the liberation of nitrate are biological, not chemical, and are accomplished by living agents, transforming organic material in their quest for energy, and continually synthesising new tissue as a result of attack on the old. Once a point of biological and nutritional stability has been reached, further nitrification is, in effect, the nitrification of living microbial tissue as and when it dies. Though individual organisms may have only a transient existence, the downgrade process seems to be but slow. Information on this phase of soil transformations is scanty and experiments bearing thereupon would have to be conducted over an extremely long period of time.

V. SUMMARY.

1. Various aspects of the availability of the nitrogen of fungal tissue to micro-organisms have been investigated, with particular reference to the influence of the C/N ratio of the material.
2. Fungal tissue was found to be as suitable a source of nitrogen as ammonium salts and nitrates for the decomposition of straw both by a mixed soil flora and by pure cultures of certain fungi.
3. The liberation of ammonia in sand culture from fungal tissue by pure cultures of reputedly active ammonifiers was measured.

164 *The Biological Decomposition of Plant Materials*

4. The nitrification in soils of a number of samples of fungus tissue was compared with that of artificial mixtures of equal C/N ratio built up from glucose, cellulose and straw, each with added inorganic nitrogen.

5. A very clear correlation was found between the C/N ratio of the fungal material and the nitrogen nitrified. In one series in hill-side soil nitrification increased from 42 to 80 per cent. in 6 months as the ratio decreased from 15.8 to 5.5; in another, from 20 to 75 per cent. as the ratio decreased from 17 to 7.

6. No evidence was found for the existence of a very resistant and unnitrifiable residue from fungal tissue as claimed by some workers, and incomplete nitrification is probably due to the attainment of biological equilibrium or of a state in which change is very slow.

The author is much indebted to E. G. Hastings, Chairman of the Department of Agricultural Bacteriology of the University of Wisconsin, for putting at his disposal the facilities of that Department, and to E. B. Fred and W. H. Peterson for their ready assistance and advice.

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(Received June 17th, 1932.)

XXXVII. THE BIOLOGICAL OXIDATION OF CARBOHYDRATE SOLUTIONS.

II. THE OXIDATION OF SUCROSE IN THE PRESENCE OF DIFFERENT INORGANIC NITROGEN COMPOUNDS.

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(Received January 5th, 1933.)

THE important rôle of nitrogen in the oxidation of carbohydrate solutions by the method known as biological filtration, *i.e.* percolation of the solution through a bed of inert material, has been studied in detail at Rothamsted by Dawson, Jenkins and Martin [unpublished work]. In later work Barritt [1931, 1] concludes that a 0.2 % solution of sucrose is most effectively oxidised by a similar method provided the initial C:N ratio is not greater than 15/1. The former workers all used either ammonium salts or albumin as the source of nitrogen, and the solutions were made up in Harpenden tap-water. This water is derived from chalk measures and besides large quantities of calcium bicarbonate contains about 1 part of total nitrogen per 100,000, 0.5 part as nitrate and 0.5 part as organic nitrogen. In previous work it was quite evident that both forms of nitrogen were utilised by the organisms which develop on percolating filters, since nitrogen-free effluents were frequently obtained.

The objects of the experiments described in this paper were: (1) to study the effect of nitrogen supplied as ammonia, nitrite and nitrate on the biological oxidation of sucrose, (2) to ascertain the changes which these nitrogenous compounds undergo in a percolating filter and (3) to examine the effect of narrow C:N ratios with the carbohydrate and nitrogen compounds chosen.

Method of experiment.

The apparatus and its method of use have been described in the preceding paper [Jenkins, 1933]. The volume of the filter was 0.0342 cu. yd., so that a rate of 7 litres per day represented a flow of 46 gallons of solution per cubic yard of filter medium per day (abbreviated g.y.d.). The filter was filled with washed and weathered clinker of $\frac{1}{4}$ " to $\frac{1}{2}$ " grade.

Solutions of sugar and mineral salts were made up daily in distilled water and the desired quantity of the nitrogen compound was added. The amounts of sugar and salts were as follows:

	g. per litre
Sucrose	1.0000 (glucose equivalent 1.053)
MgSO ₄ · 7H ₂ O	0.0071
K ₂ HPO ₄	0.0143
NaCl	0.0028
CaCl ₂ · 6H ₂ O	0.1375
Fe ₂ Cl ₆	Trace

91st to 100th day:	5 parts N per 100,000 as NaNO_3 ,	Series 1
101st to 121st day:	10	" "
122nd to 147th day:	5	" "
148th to 177th day:	10	" "
		" "
	NH_4Cl ,	" "
		" "

Results of Exp. 1.

Sugar oxidation (Table I A). The filter did not appear to be mature after the 48th day of experiment at the end of Series 1, since it continued to improve with increased time of running. At a rate of 46 g.y.d. 97.9 % of the sugar was

Table I. *Composition of solution and of effluents from different sections of the filter: parts per 100,000 nutrient solution filtered: sucrose nominally equal to 105.3 parts glucose.*

Rate of filtration = 46 g.y.d.														
Series 1 (1st to 48th day)								Series 2 (49th to 90th day)						
Average results of 5 sets of analyses made on the 16th, 30th, 41st, 45th and 48th day								Average results of 3 sets of analyses made on the 56th, 63rd and 83rd day						
Amount of nitrogen added = 5 parts per 100,000								Amount of nitrogen added = 10 parts per 100,000						
C:N ratio = 8.4:1								C:N ratio = 4.2:1						
A. Nitrogen added as sodium nitrite	Nutrient solution	Section						Nutrient solution	Section					
		1	2	3	4	5	6		1	2	3	4	5	6
Total sugars (calc. as glucose)	116.6	61.9	26.6	9.0	2.5	0.3	0.1	109.1	28.2	12.1	3.8	1.4	1.1	0.4
Sucrose (calc. as glucose)	116.6	29.7	1.8	3.7	0.9	0.1	0.0	109.1	1.8	1.2	0.8	0.3	0.6	0.2
Invert sugar (calc. as glucose)	0.0	32.2	24.8	5.3	1.6	0.2	0.1	0.0	26.4	10.9	3.0	1.1	0.5	0.2
Nitrogen as ammonia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nitrogen as nitrite	5.00	3.30	2.30	1.90	1.30	0.60	0.30	10.00	3.60	3.40	2.30	1.30	0.60	0.50
Nitrogen as nitrate	0.0	0.10	0.29	0.53	1.26	2.19	1.90	0.0	1.21	1.31	1.42	1.38	2.60	2.83
Total inorganic nitrogen	5.00	3.40	2.59	2.43	2.56	2.79	2.29	10.00	4.81	4.71	3.72	2.68	3.20	3.33
pH	6.2	7.2	7.5	7.7	7.7	7.7	7.8	—	—	—	—	—	—	—

oxidised by the first four sections, whereas in the sectional filter previously used [Jenkins, 1931] only 86.3 % of a 0.1 % solution of sugar was oxidised at the same rate of feed when the filter was mature. In the early stages of the experiment a large percentage of the total sugar appeared as invert sugar. Thus the effluent from Section 1 contained 32.2 parts of invert sugar out of a total sugar content of 61.9 parts per 100,000, while the corresponding figures for the effluent from Section 2 were 24.8 and 26.6 respectively. Owing to the unexpected efficiency of the filter little sugar remained for oxidation in the lower sections.

Table I B. It would be erroneous to conclude from a comparison of the amounts of sugar left in the effluents from Section 1 in Table I A, Series 2, and Table I B, Series 1, that the change over from nitrite to nitrate had produced a beneficial effect. The film on the filter was still young at this stage and the individual analyses from which the average figures for Section 1, Table I A, Series 1 and 2, are obtained indicate that the amount of sugar which would have been oxidised with the continued use of nitrite as the source of nitrogen would have equalled that decomposed when nitrate was subsequently employed. With both proportions of nitrate-nitrogen supplied, nearly all the sugar was oxidised in the first section.

Table I (cont.)

B. Nitrogen added as sodium nitrate	Series 1 (91st to 100th day)							Series 2 (101st to 121st day)						
	Average results of 2 sets of analyses made on the 91st and 99th day							Average results of 2 sets of analyses made on the 106th and 114th day						
	Amount of nitrogen added = 5 parts per 100,000 C:N ratio = 5.4:1							Amount of nitrogen added = 10 parts per 100,000 C:N ratio = 4.2:1						
	Nutrient solution	Section						Nutrient solution	Section					
		1	2	3	4	5	6		1	2	3	4	5	6
Total sugars (calc. as glucose)	101.1	1.4	0.4	0.4	0.4	0.4	0.3	107.9	12.5	0.6	0.0	0.0	0.0	0.0
Sucrose (calc. as glucose)	101.1	1.2	0.1	0.2	0.2	0.3	0.2	107.9	6.1	0.5	0.0	0.0	0.0	0.0
Invert sugar (calc. as glucose)	0.0	0.2	0.3	0.2	0.2	0.1	0.1	0.0	6.4	0.1	0.0	0.0	0.0	0.0
Nitrogen as ammonia	0.0	0.03	0.04	0.04	0.04	0.02	0.02	0.0	0.01	0.01	0.02	0.01	0.00	0.01
Nitrogen as nitrite	0.03	0.17	0.16	0.06	0.03	0.01	0.01	0.05	2.30	1.56	1.10	0.65	0.14	0.01
Nitrogen as nitrate	4.97	1.32	0.68	0.93	0.84	1.38	1.60	9.95	3.39	3.15	3.20	3.34	3.24	3.12
Total inorganic nitrogen	5.00	1.52	0.88	1.05	0.91	1.41	1.63	10.00	5.70	4.72	4.38	4.00	3.38	3.14
P_H	6.2	7.2	7.3	7.5	7.5	7.6	7.6	7.2	7.3	7.4	7.6	7.6	7.6	7.6

Table I C. The amount of sugar oxidised in the filter was of the same order as that oxidised when nitrate was the source of nitrogen. Mr Yates of the Rothamsted Statistical Department, has examined the individual figures of analysis and has found that no significant difference exists between the results of oxidation of sugar in the presence of ammonia, nitrite or nitrate, at any level of the biological filter if the values found during the first 48 days are excluded from the examination. The differences between the results for sugar oxidised with any one form of nitrogen were found to be greater than the differences due to the use of various forms of nitrogen.

Nitrogen results, Table I A, B and C. At the beginning of the experiment, *Table I A, Series 1*, the complete removal of 1.6 parts of N in Section 1 from

Table I (cont.)

C. Nitrogen added as ammonium chloride	Series 1 (122nd to 147th day)							Series 2 (148th to 177th day)						
	Average results of 3 sets of analyses made on the 127th, 133rd and 140th day							Average results of 3 sets of analyses made on the 148th, 155th and 177th day						
	Amount of nitrogen added = 5 parts per 100,000 C:N ratio = 8.4:1							Amount of nitrogen added = 10 parts per 100,000 C:N ratio = 4.2:1						
	Nutrient solution	Section						Nutrient solution	Section					
		1	2	3	4	5	6		1	2	3	4	5	6
Total sugars (calc. as glucose)	102.2	11.5	3.1	0.6	0.1	0.1	0.0	105.4	10.8	4.2	2.3	1.1	0.6	0.4
Sucrose (calc. as glucose)	102.2	8.4	2.7	0.3	0.1	0.1	0.0	—	4.6	0.8	0.7	0.2	0.4	0.3
Invert sugar (calc. as glucose)	—	3.1	0.4	0.3	0.0	0.0	0.0	—	6.2	3.4	1.6	0.9	0.2	0.1
Nitrogen as ammonia	5.00	3.46	3.18	3.06	3.05	2.35	1.90	10.00	8.29	7.10	6.32	5.46	4.10	2.85
Nitrogen as nitrite	—	0.02	0.00	0.00	0.00	0.01	0.02	—	0.00	0.00	0.01	0.02	0.02	0.02
Nitrogen as nitrate	—	0.00	0.00	0.04	0.21	0.36	0.78	—	0.00	0.05	0.35	1.05	2.20	4.16
Total inorganic nitrogen	5.00	3.48	3.18	3.10	3.26	2.72	2.70	10.00	8.29	7.15	6.68	6.53	6.32	7.08
P_H	6.1	6.2	6.8	7.0	7.2	7.2	7.2	6.4	6.2	6.2	6.5	6.6	6.6	6.6

5 parts supplied as nitrite was probably caused by the direct assimilation of nitrogen by the growing micro-organisms. A smaller quantity of nitrogen was taken up or destroyed in Section 2, but beyond this part of the filter, where the concentration of carbohydrate was relatively small, the function of the filter was to oxidise nitrite to nitrate. There was no appreciable loss of N in the last four units of the filter. When 10 parts of N as NaNO_2 were used 74 % of the sugar was oxidised in the first section and at the same time 1.2 parts of nitrogen as nitrate were found in the effluent. The nitrogen immobilised by the film or removed from solution in Section 1 by any other means amounted to 5.2 parts. When nitrate was used as the source of nitrogen the greatest removal of this element from the solution again occurred in Section 1, as was the case with nitrite. In Series 1, 3.5 parts N or 70 % of the total was unaccounted for in the effluent from the first section, while the corresponding figures for Series 2 were 4.3 and 43 %. The greatest utilisation of nitrate and nitrite is thus seen to occur in that part of the filter giving the highest oxidation of sugar. It is well known that micro-organisms are able to make use of oxygen in the combined state under anaerobic conditions and it is possible that some nitrogen disappeared from the nutrient solutions on passage through the filter owing to the de-oxygenation of nitrite and nitrate. As soon as the zone of vigorous carbohydrate oxidation is passed, *i.e.* beyond Section 1, loss of nitrogen from solution ceases and instead oxidation of nitrite to nitrate takes place in this part of the filter. As in the case of nitrite no more than traces of ammonia were found in the effluents from any of the sections when nitrate was used.

The results obtained with ammonium chloride show the ease of oxidation of sugar in a percolating filter, as compared with that of nitrogen. When the source of nitrogen was changed from nitrate to ammonia the filter was evidently well inoculated with organisms able to oxidise nitrite to nitrate, as shown by the results described in the previous paragraph, owing to the occurrence of nitrite in the nutrient solutions or in the effluents for a period of 121 days. However, during this period the filter had not received any appreciable quantity of ammonia. Hence the establishment of nitrite-forming micro-organisms was slow. The development of these organisms as the filter grew older and continued to receive a supply of ammonia is seen from the amounts of derived nitrate present in the final effluents in Table I C, Series 1 and 2, an average of 0.78 part and 4.16 parts respectively being obtained. Between the 122nd and 177th day of the experiment, when ammonia was added, the concentration of nitrogen as nitrite never exceeded 0.02 part per 100,000 of solution.

Increase of rate of flow from 46 g.y.d. to 186 g.y.d. The average amount of sugar oxidised by the upper one-third of the filter during the first 177 days was equal to 92.7 %. In order to extend the range in the filter of the decomposition of the carbohydrate so that sugar still appeared in the effluent from the fifth section but hardly any from the sixth, the rate of flow was increased by stages until it was four times the original rate. The effect of the greater rates of flow on the removal of carbohydrate is seen in Table II, which shows that at rates of 46, 92 and 184 g.y.d. the amounts of sugar decomposed by the first section were 92, 86 and 47 % respectively. A few tests were made at rates of 250 g.y.d. and even at this high rate of feed the oxidation of sugar effected by the whole filter amounted to over 90 %. It is interesting to note that the nitrogen present as nitrite and nitrate in the final section was 4.2 parts at 46 g.y.d. Later, when the filter was older, and presumably richer in nitrifying organisms, the increase in flow to 92 g.y.d. did not affect the time of contact sufficiently to lower the concentration of nitrite and nitrate in the effluent. On

Table II. *Effect of increase in rate of flow of sugar solution on the amount of sugar and nitrogen oxidised. Figures for sugar and nitrogen are given in parts per 100,000.*

	Rate = 46 g.y.d. Solution filtered from 141st-155th day = 100 parts sugar plus 10 parts N as NH_4Cl Analysis on March 18th					Rate = 92 g.y.d. Solution filtered from 156th-177th day = 100 parts sugar plus 10 parts N as NH_4Cl Analysis on April 9th				
	Total sugars calc. as glucose	Invert sugar calc. as glucose	Nitrogen as ammonia	Nitrite and nitrate	pH	Total sugars calc. as glucose	Invert sugar calc. as glucose	Nitrogen as ammonia	Nitrite and nitrate	pH
Nutrient solution	95.8	—	10.00	—	6.1	99.5	—	10.00	—	6.4
Effluent of Section 1	7.6	3.4	8.55	0.0	6.2	14.2	8.6	8.24	0.00	6.2
Effluent of Section 2	0.9	0.3	6.05	0.16	6.8	8.2	8.4	8.09	0.00	6.2
Effluent of Section 3	0.5	0.0	4.93	0.67	7.0	5.2	3.7	7.30	0.16	6.5
Effluent of Section 4	0.5	0.0	3.87	1.74	7.2	2.3	1.8	6.47	1.02	6.6
Effluent of Section 5	0.3	0.0	2.30	3.41	7.2	1.1	0.4	5.15	2.29	6.6
Effluent of Section 6	0.2	0.0	1.46	4.18	7.2	0.7	0.2	3.25	6.25	6.6

Rate = 184 g.y.d.
Solution filtered from 178th-182nd day = 100 parts
sugar plus 10 parts N as NH_4Cl
Analysis on April 14th

	Total sugars calc. as glucose	Invert sugar calc. as glucose	Nitrogen as ammonia	Nitrite and nitrate	pH
Nutrient solution	104.5	—	10.00	—	5.0
Effluent of Section 1	55.3	5.4	8.51	0.00	5.1
Effluent of Section 2	25.4	8.2	8.30	0.00	5.2
Effluent of Section 3	11.1	8.4	7.92	Trace	6.0
Effluent of Section 4	4.8	5.0	7.45	0.60	6.0
Effluent of Section 5	2.0	1.3	6.85	1.09	6.4
Effluent of Section 6	0.4	0.2	5.09	1.48	6.3

the contrary this increased to 6.3 parts N as nitrite and nitrate. A further rise in the rate to 184 g.y.d. depressed the amount of nitrite and nitrate produced in relation to the carbohydrate oxidised, probably because at this rate of flow the time of contact of solution with the organic film was less than the optimum required to oxidise ammonia.

Exp. 2.

After it had been shown that a 0.1 % solution of sugar could be almost completely oxidised in the percolating filter at a rate of 184 g.y.d. this rate was chosen for a second experiment in which the solutions were filtered in the following order:

From 178th to 196th day:	10 parts N as NH_4Cl	per 100,000 of solution
197th to 209th day:	5	" "
210th to 261st day:	10	" NaNO_3 "
262nd to 279th day:	5	" " "
280th to 296th day:	10	" NaNO_2 "
297th to 302nd day:	5	" " "

Results of Exp. 2.

(Table III shows the results obtained in this experiment.)

Table III. *Composition of solution and of effluents from different sections of the filter: parts per 100,000. Nutrient solution filtered: sucrose nominally equal to 105.3 parts glucose.*

Rate of filtration = 184 g.y.d.														
Series 1 (178th to 196th day)								Series 2 (197th to 209th day)						
Average results of 3 sets of analyses made on the 182nd, 189th and 196th day								Average results of 2 sets of analyses made on the 202nd and 209th day						
Amount of nitrogen added = 10 parts per 100,000 C:N ratio = 4.2:1								Amount of nitrogen added = 5 parts per 100,000 C:N ratio = 8.4:1						
A. Nitrogen added as ammonium chloride	Nutrient solution	Section						Nutrient solution	Section					
		1	2	3	4	5	6		1	2	3	4	5	6
Total sugars (calc. as glucose)	106.0	51.6	20.0	10.7	5.0	2.2	0.5	109.4	59.0	27.4	11.1	6.1	2.6	0.9
Sucrose (calc. as glucose)	106.0	43.8	15.3	4.8	1.5	1.1	0.3	109.4	53.9	21.6	4.7	1.3	0.5	0.4
Invert sugar (calc. as glucose)	—	7.8	4.7	5.9	3.5	1.1	0.2	—	5.1	5.8	6.4	4.8	2.1	0.5
Nitrogen as ammonia	10.00	8.71	8.19	8.16	7.92	6.83	6.26	5.00	3.75	3.99	3.82	3.65	3.55	2.63
Nitrogen as nitrite	—	0.00	0.00	0.00	0.00	0.00	0.00	—	0.00	0.00	0.00	0.00	0.00	0.00
Nitrogen as nitrate	—	0.00	0.00	0.00	0.29	0.38	1.30	—	0.00	0.00	0.00	0.00	Trace	0.66
Total inorganic nitrogen	10.00	8.71	8.19	8.16	8.21	7.21	7.56	5.00	3.75	3.99	3.82	3.65	3.55	3.29
p _H (one determination)	5.0	5.1	5.2	6.0	6.0	6.4	6.3	—	—	—	—	—	—	—
Series 1 (210th to 261st day)								Series 2 (262nd to 279th day)						
Average results of 5 sets of analyses made on the 216th, 218th, 239th, 251st and 261st day								Average results of 2 sets of analyses made on the 267th and 273rd day						
Amount of nitrogen added = 10 parts per 100,000 C:N ratio = 4.2:1								Amount of nitrogen added = 5 parts per 100,000 C:N ratio = 8.4:1						
B. Nitrogen added as sodium nitrate	Nutrient solution	Section						Nutrient solution	Section					
		1	2	3	4	5	6		1	2	3	4	5	6
Total sugars (calc. as glucose)	103.0	58.6	34.3	23.8	16.4	10.0	5.8	96.1	59.0	30.1	16.6	12.0	4.8	0.8
Sucrose (calc. as glucose)	99.8	50.3	24.7	13.3	5.7	2.5	1.5	94.4	54.9	25.6	13.2	10.0	3.9	0.4
Invert sugar (calc. as glucose)	3.2	8.3	9.6	10.5	10.7	7.5	4.3	1.7	4.1	4.5	3.4	2.0	0.9	0.4
Nitrogen as ammonia	0.01	0.05	0.08	0.14	0.14	0.15	0.18	0.03	0.02	0.02	0.01	0.01	0.02	0.02
Nitrogen as nitrite	0.01	0.86	0.91	0.91	0.88	0.72	0.68	0.53	0.43	0.50	0.55	0.50	0.55	0.29
Nitrogen as nitrate	9.98	5.98	4.34	3.43	3.25	2.82	2.60	4.44	1.41	1.15	0.73	0.52	0.47	0.32
Total inorganic nitrogen	10.00	6.89	5.33	4.48	4.27	3.69	3.46	5.00	1.86	1.67	1.29	1.03	1.04	0.63
p _H	5.9	6.1	6.3	6.3	6.6	6.9	7.0	5.6	6.8	6.6	6.8	6.8	7.0	7.1

Sugar oxidation. Since on statistical examination all the six sets of results do not show any significant difference it may be concluded that sufficient nitrogen is provided for the organisms in the filter with a C:N ratio of 8.4:1 or less. There is ample evidence [unpublished work of Dawson, Jenkins and Martin] and Barritt [1931, 1] that carbohydrate solutions of C:N ratio greater than 8.4:1 can be oxidised efficiently on percolating filters. Table III also

Table III (*cont.*)

C. Nitrogen added as sodium nitrite	Series 1 (280th to 296th day)								Series 2 (297th to 302nd day)							
	Average results of 5 sets of analyses made on the 283rd, 288th, 290th, 293rd and 296th day Amount of nitrogen added = 10 parts per 100,000 C:N ratio = 4.2:1								Average results of 2 sets of analyses made on the 300th and 302nd day Amount of nitrogen added = 5 parts per 100,000 C:N ratio = 8.4:1							
	Nutrient solution	Section						Nutrient solution	Section						Nutrient solution	Section
		1	2	3	4	5	6		1	2	3	4	5	6		
Total sugar (calc. as glucose)	103.3	43.1	17.9	10.0	4.6	1.2	0.5	106.9	66.0	34.2	15.9	4.9	1.3	0.6		
Sucrose (calc. as glucose)	101.5	36.9	13.3	7.0	3.4	0.9	0.2	106.2	59.4	27.3	12.8	3.6	0.0	0.3		
Invert sugar (calc. as glucose)	1.8	6.2	4.6	3.0	1.2	0.3	0.3	0.7	6.6	6.9	3.1	1.3	1.3	0.3		
Nitrogen as ammonia	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
Nitrogen as nitrite	9.98	5.47	2.43	1.33	0.81	0.51	0.27	5.00	2.55	0.70	0.11	0.01	0.00	0.00		
Nitrogen as nitrate	0.00	0.26	0.24	0.48	0.72	0.72	0.84	0.00	0.04	0.63	0.13	0.24	0.07	0.13		
Total inorganic nitrogen	10.00	5.75	2.67	1.81	1.53	1.23	1.11	5.00	2.59	1.33	0.24	0.25	0.07	0.13		
<i>pH</i>	6.5	6.9	6.8	6.9	7.0	7.2	7.3	6.5	6.6	6.6	6.6	6.7	6.9	7.0		

proves that when the C:N ratio provides enough available nitrogen for microbiological requirements under the conditions of the experiment it does not matter whether the nitrogen is supplied as nitrite, nitrate or ammonia. A supply of nitrogen in excess of the needs of the film has no measurable effect on the oxidation of sugar.

The proportion of invert sugar in the total sugar contained in the effluents from the sections in Exp. 2 was considerably less than in the corresponding effluents during Exp. 1. The results of the latter experiment showed the highest percentage of invert sugar to be present in the effluents of the upper sections when nitrite was used, *i.e.* at the start of the experiment. As the filter grew older the amount of invert sugar in solution became less, falling from 32.2 parts in Section 1, Table I A, Series 1, to 6.2 parts in Section 1, Table I C, Series 2, and to 6.6 parts in Section 1, Table III C, Series 2. Hence it appears that the presence of large quantities of invert sugar in the effluents of a percolating filter is indicative of a state of immaturity.

Nitrogen results. The absence of nitrite from all the effluents obtained when ammonium chloride was supplied at the high rate of flow in Exp. 2 and the small amount of nitrate produced support the view previously advanced in this paper that the oxidation of nitrogen is sensitive to changes in rate of flow or time of contact. Nitrate did not appear until the fourth section had been reached when 10 parts of ammonia-nitrogen were supplied while only 0.66 part N as NO_3 was obtained in the last section when 5 parts were added. Including nitrogen immobilised by the micro-organisms, an average of 30 % of the nitrogen fed as ammonium chloride was unaccounted for in the final effluents.

The results shown in Table III B resemble those obtained with sugar and nitrate at a rate of 46 g.y.d. (Table I B) in that nitrite was found in the effluents from all sections. At the lower rate of flow, however, the reduction of nitrate to nitrite was most vigorous in the first section of the filter where carbohydrate oxidation was also greatest. In both series of Exp. 2 the amounts of nitrogen removed from the solutions by Section 1 were significantly lower when am-

monium chloride was the source of nitrogen than was the case when either sodium nitrite or sodium nitrate was supplied. Thus the percentages of nitrogen unaccounted for in the effluent of Section 1 when 10 and 5 parts respectively of ammonium chloride were present amounted to 13 and 25 respectively, the corresponding figures for nitrite being 43 and 48, and for nitrate 31 and 63. These figures indicate that either (1) more nitrogen is used to build up the film in a filter when nitrite or nitrate is supplied than if ammonia is used or (2) that nitrite and nitrate play a part in the oxidation of sugar which ammonia does not. If there is any truth in the latter speculation the additional rôle of nitrite and nitrate as suppliers of oxygen for the combustion of sugar did not result in any significant difference in the amount of carbohydrate oxidised by all the three forms of nitrogen used. The apparent loss of nitrogen in Exp. 2 was considerable, an average of 76 % being recorded during the period of 70 days when nitrogen was provided as sodium nitrate.

A large proportion of the nitrite supplied from the 280th to 296th day could not be accounted for in the effluents. Only 58 % was recovered in the effluent of Section 1 and this figure fell to 11 % in the final effluent. At this stage of the experiment there did not appear to be the increase in the amount of film produced which would have been expected if there had been a quantitative conversion into microbial tissue of all the nitrogen unaccounted for in the effluents. In all the sections nitrate was found, so that oxidation of carbohydrate and of nitrite had occurred simultaneously. The amount of inorganic nitrogen which was not recovered in the final effluents reached an average figure of 94 % for the 23 days of this part of the experiment.

DISCUSSION OF RESULTS.

It is a well-established fact that micro-organisms require nitrogen for their growth. The result of the two experiments which have been described in this paper show that in oxidising sugar by biological filtration the organisms concerned are able to use nitrogen as ammonium chloride, sodium nitrite or sodium nitrate with equal efficiency.

As yet there does not appear to be any means of determining the availability of a nitrogenous compound under the conditions of a biological filter other than the tedious one of putting the compound through a prolonged filtration test. Degrees of availability of different nitrogenous substances may exist; in connection with the decomposition of plant materials Richards and Norman [1931] state that, "Plant materials already containing sufficient or more than sufficient nitrogen for decomposition may nevertheless immobilise an additional amount, owing to preferential utilisation of the inorganic form." The availability of organic sources of nitrogen such as fungal tissues has been studied by Norman [1933] and compared with the availability of various inorganic sources of nitrogen. Organic forms of nitrogen may be assimilated by organisms just as readily as inorganic forms and, as in the case of albumin [Jenkins, unpublished work] may actually possess certain advantages over, say, ammonium salts by increasing the time of contact of a new filter. For practical reasons, however, nitrogen is best supplied as ammonia since in this form relatively little loss of nitrogen appears to result. Other nitrogenous compounds, such as those present in the effluents from the pulp presses of beet-sugar factories seem to be only slowly decomposed and temporarily immobilised before being utilised by micro-organisms.

In a previous paper [Jenkins, 1931] the author described experiments with a filter of fixed sections separated by air spaces and found that the maximum amount of invert sugar obtained from 100 parts of sucrose was 15 parts in the effluent of Section 4. When this filter reached its maximum efficiency some of the effluents contained nearly 11 parts of invert sugar. The results obtained in the present work, however, suggest that the products of inversion appear in large amounts in a new filter but do not persist except in comparatively small amounts in a mature filter. Compared with the improved wooden sectional filter used for this work the fixed sectional filter was inefficient, as it could only oxidise considerably less than one-half the amount of sugar oxidised by the former.

The p_H figures of the effluents which were recorded during these experiments showed that there was generally no measurable production of acid on filtration. The only reductions of p_H observed during both experiments were small and possibly insignificant in amount, *viz.* from 6.4 to 6.2 in Table I C, from 6.4 to 6.2 and 6.4 to 6.3 in Table II, from 6.4 to 6.3 in Table III A, from 6.8 to 6.6 in Table III B, and from 6.9 to 6.8 in Table III C.

The nutrient solutions, as previously mentioned, were made up daily in distilled water. Since the aspirators in which the solutions were kept occasionally contained microbial growths, in spite of daily cleaning, inversion of the sugar sometimes occurred to a small extent. This inversion could be ignored when compared with the amount of hydrolysis of the sugar on filtration. As much as 50 % of the sugar in the effluents from Sections 1 and 2 was present in the invert form when the filter was immature. Later, when the efficiency of the film increased, less invert and less total sugar were found. It is of interest to know that a young film may be so active in effecting the first stage of carbohydrate degradation, *viz.* hydrolysis.

In a filter able to oxidise completely the sucrose presented to it the ratio of invert to total sugar in any section appears to be small, presumably because the invert sugar is then decomposed as rapidly as it is formed. Maximum efficiency in a percolating filter is reached as the filter ages. In this respect the conditions in a filter differ from those which exist in a pure culture of organisms, where biological activity falls off with the age of the culture. The population of a biological filter becomes more varied with continued operation. Although the flora of the film rarely remains the same over a long period [unpublished work of Cutler, Crump, Dixon and Sandon] it is believed that any changes in its biological composition are in the direction of a more varied and specialised population, each organism specialising in those reactions which it is able to carry out in the presence of other competing organisms.

In the early stages of development a filter requires an ample supply of nitrogen, besides other elements, for the growth of its population. Once an active film has been established nitrogen is still required, but in smaller quantities. It is in fact only necessary to replace the losses of nitrogen which are known to occur either through denitrification or by the removal of dead organisms. The results given in the Tables point to losses of nitrogen far in excess of the quantity which would be required to maintain the growth of the film. The disappearance of nitrogen is seen to be most marked in the case of sugar solutions which contained nitrite or nitrate. For instance in Table III C, Series 1, 10 parts of nitrogen per 100,000 were reduced to 5.75 parts in the first section of the filter. This is equivalent to a removal of 0.021 % NaNO_2 from a solution originally containing 0.049 %. Now it is possible by physical methods to determine the average time during which the solution is in contact with

the film [Clifford, 1907]. Measurements of the time of contact on the filter under discussion have not been made, but from numerous experiments carried out with percolating filters filled with the same size of clinker it is estimated that at a rate of 184 g.y.d. the average time of passage of the nutrient solution through the first section would be between $\frac{3}{4}$ and 1 hour. In the time taken to percolate through the six sections of the filter, say about 4 hours¹, 0.044 % of the sodium nitrite in the solution originally containing 0.049 % had been decomposed. At first sight it appears that this rapid denitrification, which occurs immediately the nutrient solution is run on to the filter, conflicts with the results of Lloyd and Cranston [1930]. These workers found that under anaerobic conditions in pure culture a denitrifying marine organism isolated from Loch Striven completely denitrified a 0.313 % solution of KNO_2 in about 60 hours. However, there was an initial lag phase of 18 hours before gas production occurred. Under natural conditions, when the organisms were developing normally this lag phase would be reduced or disappear entirely. Moreover, it is not at all unlikely that the rate of evolution of gas would be increased in a natural environment owing to the stimulating action of other organisms [Cutler and Crump, 1929; Meiklejohn, 1930]. As previously mentioned a considerable quantity of nitrogen was unaccounted for in the effluents when solutions of ammonium chloride and sugar were filtered. Although the amount which disappeared in this case was less than the losses with nitrite and nitrate it is possible that the continuous removal of large amounts of ammonia from solution might be due to some loss of gaseous nitrogen in addition to the nitrogen taken up by the film. The data given in this paper, however, cannot be taken as proof of the loss of nitrogen in the free state.

The causes of denitrification under varying experimental conditions have been studied by several workers. Many soil bacteria such as *Bact. mycoides* [Marchal, 1893] are able to transform nitrates into ammonia with nitrites as intermediate compounds, while others can only reduce nitrates to free nitrogen. Muntz and Lainé [1911] found that denitrification occurs in percolating filters when readily oxidisable organic matter and nitrates are treated on such filters. These workers observed a loss of 60 % nitrate in several experiments. A nitrogen balance sheet of the bio-aeration method of sewage purification was drawn up by Richards and Sawyer [1922] who attributed losses of nitrogen in the process to the simultaneous presence of organic matter and oxidised forms of nitrogen. Although it has been believed that both amino-acids and nitrites lose free nitrogen when they interact in the presence of micro-organisms, Barritt [1931, 2] has shown that it is only the nitrite which suffers denitrification. There is no experimental evidence to support the view sometimes put forward [Waksman, 1931] that denitrification under natural conditions may result from the union of ammonia and nitrous acid, followed by the decomposition of the ammonium nitrite thus formed into nitrogen and water. The results obtained with the Scott-Moncrieff [1909] sectional biological filter do not support this opinion.

The results given in this paper agree with those found by other workers in showing that denitrification is most vigorous in the presence of decomposable organic matter. Decomposition of nitrite in a percolating filter is not inhibited by the presence of oxygen. In the present experiments the solutions in which denitrification was active contained between 0.4 and 0.6 part per 100,000 of dissolved oxygen and being spread over the surface of the clinker in thin films

¹ The time of percolation through six sections would not be six times that of the first section because the large quantity of film in this section offers a relatively greater resistance to the passage of liquid. Section 1 would thus give a longer time of contact than any other part of the filter.

the liquids were constantly exposed to a supply of air. Oxygen tension has a greater effect in arresting nitrate reduction in pure culture than in percolating filters. For instance Stickland [1931] found that *Bact. coli* reduces nitrates quantitatively to nitrite under anaerobic conditions. This investigator found that it required only 3.8 % saturation of dissolved oxygen in the culture medium to cause a 93 % decrease of this reduction, whereas in the experiments with percolating filters described in this paper vigorous reduction occurred when the oxygen tension was as high as 60 % of saturation. The extent of the loss of nitrogen depends mainly upon the C:N ratio but also upon the type of nitrogen compound. If this ratio is large and nitrogen compounds other than nitrates or nitrites are absent, the nitrogen supplied may be used entirely for structural purposes and so locked up in the filter. With a small C:N ratio some nitrogen may remain unaccounted for, even when due allowance has been made for microbiological requirements; this is especially likely if the source of nitrogen is nitrite or nitrate.

Unpublished work by Dawson, Jenkins and Watkins has shown that a 0.1 % solution of sucrose may be completely oxidised on percolating filters if a C:N ratio of about 25:1 is maintained. This agrees reasonably well with the ratio of 15:1 which Barritt [1931, 1] considers necessary for 0.2 % sucrose solutions. Under the conditions of experiment described in this paper the same results for sugar oxidation were obtained with C:N ratios of 4.2:1 as with 8.4:1. Obviously both these ratios supply more nitrogen than is required to obtain the maximum oxidation of sugar. It is improbable that any greater rate of purification of organic matter can be expected by decreasing a C:N ratio already providing a large proportion of available nitrogen.

SUMMARY.

1. A percolating filter of new design was used to compare the extent of sucrose oxidation in the presence of ammonium chloride, sodium nitrite and sodium nitrate. The differences in degree of oxidation were not significant and it is concluded that none of the forms of nitrogen has any outstanding advantage as far as sugar oxidation is concerned. With all three compounds of nitrogen the filter oxidised 28 litres of 0.1 % sucrose solution every day for 4 months (equivalent to a rate of 184 gallons per cubic yard per day (g.y.d.).

2. If the ratio of invert sugar to sucrose in the effluents of a filter receiving sucrose is high, it is probable that the filter is immature or that it is not working up to its capacity.

3. Under the conditions of filtration in these experiments there was a considerable disappearance of nitrogen from solutions having C:N ratios of 8.4:1 and 4.2:1, irrespective of the form in which the nitrogen was supplied. The greatest disappearance of nitrogen occurred with nitrite, when 97 % was removed from solution. The least occurred with ammonia-nitrogen, when 24 % was removed from solution. The apparent loss of nitrogen supplied as nitrite and nitrate and, to a smaller extent as ammonium chloride, was most marked in that part of the filter where carbohydrate oxidation was most active. These figures for apparent losses of nitrogen include the nitrogen immobilised by the film and without further experiment it is impossible to state how much, if any, of the nitrogen is actually lost as elementary nitrogen from the system.

The investigation described in this paper was carried out as part of the programme of the Water Pollution Research Board of the Department of

Scientific and Industrial Research and the results are published by permission of the Department. The work was supervised by Mr E. H. Richards to whom the author is indebted for encouragement and criticism. Thanks are due to Miss Crump, Miss Dixon, Messrs Cutler, Dawson, Martin, Sandon and Watkins whose unpublished results have been mentioned.

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[FROM THE BIOCHEMICAL JOURNAL, Vol. XXVII, No. 1, pp. 258-273, 1933]

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XXXVIII. THE BIOLOGICAL OXIDATION OF CARBOHYDRATE SOLUTIONS.

III. NITROGEN, PHOSPHORUS AND POTASSIUM BALANCES IN PERCOLATING FILTERS.

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(Received January 5th, 1933.)

THE liberation of elementary nitrogen from its compounds is a process which has been observed in many biological environments. It is reported to occur in soils rich in nitrogenous organic substances and especially in tropical soils [Meggett, 1923-25]. Manure heaps are also known to evolve free nitrogen in addition to large amounts of ammonia [Pfeiffer *et al.* 1897]. Similar losses of gaseous nitrogen have been shown by Richards and Sawyer [1922] to occur in the activated sludge or bio-aeration process for purifying sewage. Muntz and Lainé [1911] drew up a balance sheet for nitrogen in a mixture of sewage and nitrate and recorded considerable losses of nitrogen. The only evidence which exists to point to a similar phenomenon in percolating filters is purely circumstantial. Adeney and Letts [1908] found the concentration of nitrogen in the effluent from a percolating filter to be greater than in the sewage before treatment. The addition of nitrate to sewage followed by filtration through soil [Muntz and Lainé, 1911] resulted in a loss of nitrogen from the solution considerably in excess of the amount retained by the soil. A percolating filter fed with a solution of sucrose having a C:N ratio of 100:1 was found by Barritt [1931, 1] to gain about 30% of nitrogen. The solutions used by this author were made up in Harpenden tap-water, which contains a variable amount of nitrogen as nitrate. Thus Barritt found 8 parts of nitrogen as nitrate in one million parts of water while at a different time the author found the water to contain 5 parts of nitrogen as nitrate and from 5 to 7 parts in the organic form. However, even when allowance is made for these variations in the composition of the diluting water, the gain in nitrogen is quite appreciable and agrees with the conclusions of several workers [Hutchinson and Richards, 1921; Hutchinson, 1918-19] that soils and fermenting carbohydrates fix nitrogen most actively under conditions of nitrogen starvation. The author observed in previous experiments [Jenkins, 1933, 2] that under certain conditions nitrogen was apparently lost from solution during biological filtration whether ammonia, nitrite or nitrate were the source of nitrogen. The object of the experiments described in this paper was primarily to check this conclusion by drawing up balance sheets for nitrogen from the data yielded by filters operated under controlled conditions. Secondary objects were to find the phosphate and potash requirements of the biological film and the ratio of carbon oxidised to carbon compounds synthesised and the loss of moisture by evaporation during filtration.

A special technique was required to ensure freedom from available forms of nitrogen, phosphorus and potassium in the filter medium and for this purpose sectional glass filters and glass media were used. The constructional details of these experimental filters have been described elsewhere [Jenkins, 1933, 1]. The medium employed in Exp. 1 differed from that used in Exp. 2, while in Exp. 3 the filters used were of a semi-commercial size and the liquids filtered consisted of effluents from a beet-sugar factory. These three experiments are therefore considered separately.

Exp. 1. The filter consisted of 6 glass sections, 7" deep and $3\frac{1}{4}$ " in diameter, containing $\frac{1}{4}$ " to $\frac{1}{16}$ " graded glass made from broken bottles.

Solution filtered:	Sucrose ...	...	...	1 g.
	MgSO ₄ , 7H ₂ O ...	...	...	0.0131 g.
	CaCl ₂ , 6H ₂ O ...	...	...	0.0131 g.
	NaCl ...	...	...	0.0013 g.
	P ₂ O ₅ (as K ₂ HPO ₄) ...	...	...	0.0300 g.
	K ₂ O (as K ₂ HPO ₄) ...	...	...	0.0398 g.
	N as NH ₄ Cl ...	...	...	0.0500 g.
	Distilled water ...	...	...	1 litre
	C:N ratio ...	...	...	8.4:1
	p _H ...	...	...	6.0

Two litres of this solution were made up daily and run on to the filter at a rate of 100 gallons of solution per cubic yard of filtering material per day (abbreviated g.y.d.) for a period of 108 days. Additional K₂O as K₂SO₄ was supplied from the 21st to the 66th day, bringing the total K₂O to 0.0668 g. per litre. This additional K₂O was supplied to ensure an excess of potash. When the quantity given in the first place was found to be ample the addition of the extra K₂O was discontinued. Until the 66th day of the experiment the source of N was NH₄Cl; later NH₄HCO₃ was used. In glass filters none of the free acid liberated by the removal of NH₃ from the ammonium salt is neutralised, and as a result the p_H value with NH₄Cl may fall to 3.0 and check the development of organisms in the lower sections of the filter. This drop in p_H has been proved to be due chiefly, if not entirely, to the liberation of mineral acid, since the p_H of the solution undergoing treatment was never lowered when the source of nitrogen was NH₄HCO₃.

Records were kept of the total volume filtered daily and the volume of effluent obtained. At the end of the experiment, when the filters were dismantled for analysis of the film, the quantity of water retained by the medium and film was determined. Representative samples of effluent were collected and analysed each day for sugar and each week for nitrogen, phosphorus and potash. Tests were also carried out for nitrite and nitrate, while approximate measurements of the dissolved organic matter were made by the test for "biochemical oxygen demand" in 5 days [Ministry of Health, 1929]. The methods of analysis were similar to those previously described [Jenkins, 1933, 2]. The film adhering to the medium was washed off at the conclusion of the experiment and analysed immediately for organic matter, N, P and K. Nitrogen was determined by the Kjeldahl method; phosphorus was determined by digesting the concentrated solution of effluent as in the Kjeldahl method, precipitating the phosphorus as magnesium ammonium phosphate and then weighing the phosphorus as Mg₂P₂O₇; potassium was estimated by the perchlorate method.

The amounts of sugar oxidised expressed as percentages of the quantity supplied are given graphically in Fig. 1 and show that complete oxidation was

being achieved after the filter had been in operation for 20 days. After the 55th day, however, film growth prevented the free passage of solution and air through the filter, which could not be operated continuously without pools forming on the surface. Balance sheets for volume of liquid and weight of nitrogen, phosphorus and potassium were drawn up and the results are given in Tables I-IV. It is noteworthy that less than 2% of the solution was lost by evaporation over a period of 108 days; this result is confirmed by later work (see Exp. 2).

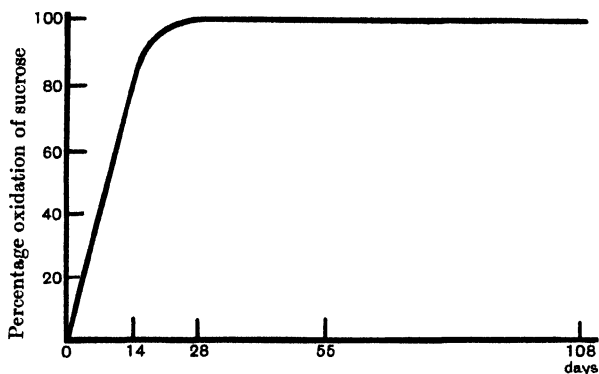


Fig. 1. Oxidation of sugar in Exp. 1.

Table I. *Preliminary experiment with C:N ratio = 8.4:1.*
Volume balance sheet (Exp. 1).

Period days	Volume filtered cc.	Volume recovered as effluent cc.	Volume retained by filter <i>plus</i> vol. lost by evaporation cc.
0-6	9,913	9,765	148
7-13	11,087	10,882	205
14-20	11,470	11,231	239
21-27	12,123	11,964	159
28-34	11,284	11,118	166
35-41	11,050	10,872	178
42-48	9,413	9,188	225
49-55	8,958	8,711	247
56-69	10,088	9,945	143
70-84	12,569	12,236	333
85-108	11,682	11,249	433
Total	119,637	117,161	2476

Liquid in filter = 352
Loss by evaporation = 2124 = 1.8 %

The figures for nitrogen show a loss of 14.2 % of the total supplied. Since neither nitrite nor nitrate formation in the filter was observed during the experiment, and the heavy growth of film rendered such oxidation of ammonia most unlikely, it is improbable that the nitrogen lost was caused by the formation of nitrite or nitrate, followed by the interaction of either compound with organic matter and the subsequent liberation of gaseous nitrogen. Moreover, as the liquids filtered were always acid (p_H 6.0 or less) the loss of over 14 % of nitrogen could not have resulted from the volatilisation of ammonia. It will be observed that the film in the third section contained more nitrogen than that in the second section. The amount of film is usually greatest in the top of the filter and decreases in quantity to the bottom. A steady decrease in amount of film

Table II. *Preliminary experiment with C:N ratio = 8.4:1.*
Nitrogen balance sheet (Exp. 1).

Period days	Nitrogen added as NH ₄ Cl or NH ₄ HCO ₃ g.	Nitrogen recovered in effluent, g.			Section No.	Nitrogen recovered in film, g.		
		Total N	NH ₃ - N	Organic N		Total N	NH ₃ - N	Organic N
0-6	0.4956	0.4328	0.4221	0.0107	1	0.3464	0.0536	0.2928
7-13	0.5544	0.1840	0.1411	0.0429	2	0.0635	0.0158	0.0477
14-20	0.5735	0.2327	0.2008	0.0319	3	0.1433	0.0294	0.1139
21-27	0.6061	0.4218	0.3999	0.0219	4	0.0728	0.0163	0.0565
28-34	0.5642	0.5132	0.5005	0.0127	5	0.0711	0.0147	0.0564
35-41	0.5525	0.2368	0.2306	0.0062	6	0.0759	0.0209	0.0550
42-48	0.4707	0.2103	0.1976	0.0127	Total	0.7730	0.1507	0.6223
49-55	0.4479	0.3056	0.2187	0.0869				
56-69	0.5044	0.4925	0.4175	0.0750				
70-84	0.6284	0.6890	0.5570	0.1320				
85-108	0.5841	0.6415	0.5575	0.0840				
Total	5.9818	4.3603	3.8433	0.5180				

Nitrogen recovered = 4.3603 + 0.7730 = 5.1333 g.

Nitrogen unaccounted for = 5.9818 - 5.1333 = 0.8485 = 14.2 %

Table III. *Preliminary experiments with C:N ratio = 8.4:1.*
Phosphorus balance sheet (Exp. 1).

Period days	P ₂ O ₅ added in nutrient solution g.	P ₂ O ₅ recovered in effluent g.	Section No.	P ₂ O ₅ recovered in film g.
0-6	0.2974	0.2226	1	0.1413
7-13	0.3326	0.1498	2	0.0274
14-20	0.3441	0.1325	3	0.0250
21-27	0.3637	0.2327	4	0.0144
28-34	0.3385	0.3048	5	0.0517
35-41	0.3315	0.1906	6	0.0177
42-48	0.2824	0.1875	Total	0.2775
49-55	0.2687	0.1778		
56-69	0.3026	0.2701		
70-84	0.3771	0.4184		
85-108	0.3505	0.4375		
Total	3.5891	2.7243		

P₂O₅ recovered = 2.7243 + 0.2775 = 3.0018 g.

P₂O₅ unaccounted for = 3.5891 - 3.0018 = 0.5873 g.

Table IV. *Preliminary experiments with C:N ratio = 8.4:1.*
Potash balance sheet (Exp. 1).

Period days	K ₂ O added in nutrient solution g.	K ₂ O recovered in effluent g.	Section No.	K ₂ O recovered in film g.
0-6	0.3954	0.3913	1	0.0610
7-13	0.4412	0.3743	2	0.0132
14-20	0.4564	0.3244	3	0.0206
21-27	0.8099	0.6142	4	0.0097
28-34	0.7538	0.8110	5	0.0108
35-41	0.7381	0.6818	6	0.0147
42-48	0.6288	0.5799	Total	0.1300
49-55	0.5984	0.4358		
56-69	0.5852	0.3908		
70-84	0.5002	0.6534		
85-108	0.4659	0.4427		
Total	6.3714	5.6996		

K₂O recovered = 5.6996 + 0.1300 = 5.8296 g.

K₂O unaccounted for = 6.3714 - 5.8296 = 0.5418 g.

was not found in this experiment because film which stuck on to the bottom of the basal plate of Section 2 was included with the medium in Section 3 in order to avoid loss of organic matter when dismantling the filter for analysis.

The apparent incomplete recovery of phosphorus and potash may be attributed largely to errors involved in the gravimetric methods of analysis employed for the small quantities of these substances. The results for the amounts contained in the effluents and in the film should probably be about 10 % greater than the figure given. The actual results of analysis showed that the film contained 2.3 % P_2O_5 and 1.1 % K_2O on the dry weight since 11.87 g. of film were contained in the whole filter.

Exp. 2. The grade of medium used in Exp. 1 was evidently too small as ponding of liquid on the top surface of the filter occurred in the later periods of the experiment. In some new filters which were constructed [Jenkins, 1933, 1] short lengths of glass tubing 1 cm. diameter by 1.5 cm. length were found to be more satisfactory as filtering medium than the graded glass from bottles used in Exp. 1. Filters were accordingly filled with short lengths of glass tubing for Exp. 2. This experiment was begun before the conclusion of the previous experiment. The objects of Exp. 2 were the same as those of Exp. 1, viz. to draw up a balance sheet for the amount of nitrogen supplied to a percolating filter and the amount recovered in the film and in the effluents, and also to obtain similar balances of phosphorus and potassium. In Exp. 2, however, two filters were used and these were supplied with solutions of sugar and ammonium bicarbonate so as to provide C:N ratios of 8.4:1 and 84:1 respectively. The details of the experiment are described below. The filters used each consisted of four glass cylinders, 18 cm. long and 8 cm. in diameter containing the glass tubes. They were fed daily with 2 litres of the following solution, i.e. at 100 g.y.d.

	Filter A C:N ratio = 8.4:1	Filter B C:N ratio = 84:1
Sucrose	1 g.	1 g.
$MgSO_4 \cdot 7H_2O$	0.0131 g.	0.0131 g.
$CaCl_2 \cdot 6H_2O$	0.0131 g.	0.0131 g.
$NaCl$	0.0013 g.	0.0013 g.
P_2O_5 (as K_2HPO_4)	0.0300 g.	0.0300 g.
K_2O (as K_2HPO_4)	0.0398 g.	0.0398 g.
N (as NH_4HCO_3)	0.0500 g.	0.0050 g.
Distilled water	1 litre	1 litre
pH	6.0	6.0
Experimental period	58 days	70 days

The filters were operated simultaneously and the same methods of sampling and analysis were used as in Exp. 1. Filter A was dismantled after 58 days and analyses were made immediately. Filter B was operated for 12 days longer so that the analytical periods would not overlap.

The percentages of sugar oxidised in Filters A and B are shown graphically in Fig. 2. While the former produced an almost sugar-free effluent after 12 days and continued to do so even after the rate of feed of sugar solution was doubled, Filter B was extremely erratic in the quantity of sugar it oxidised. It almost seems as if there existed a periodicity of sugar oxidation in which maximum combustion was attained every 4th or 5th day. The oscillation in efficiency of this filter was still marked but not quite so striking when the rate was increased to 200 g.y.d., although the rate of flow, composition of nutrient solution and other experimental details were the same from day to day. It is extremely improbable that the causes of the fluctuation in the amount of sugar found in the effluent from day to day were methodical errors, since the rate of feed of

the nutrient solution and the concentrations of sugar in these liquids were kept constant, while determinations of sugar were made on the whole of the effluent collected in one day. The daily variation in the percentages of sugar oxidised must therefore result from daily differences in the biological activity of the micro-organisms in the filter as regards the oxidation of sugar. In order to show that the composition of the effluent remains constant over a period of several hours when supplied with a nutrient liquid of constant composition at a steady rate of flow, sampling at frequent intervals would have been necessary. The chief object of the experiment, as has been stated previously, was to obtain a complete recovery of nitrogen in the film and effluents and as the removal of samples at short intervals of time for the determination of sugar would have

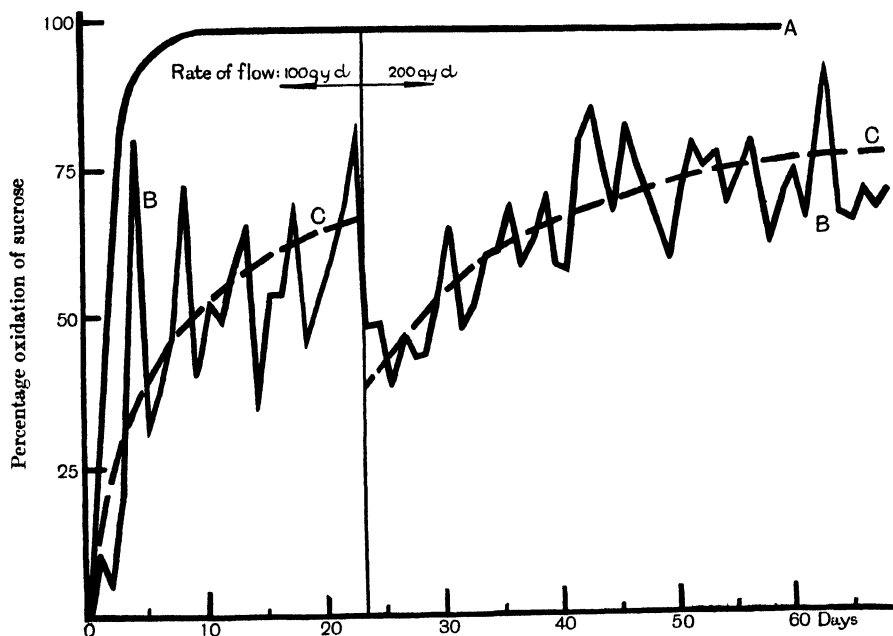


Fig. 2. Percentage oxidation of sugar by filter receiving C:N ratios of 8.4:1 and 84:1 respectively (Exp. 2). A: Filter fed with a solution of 100 parts of sucrose, 3 parts P_2O_5 (K_2HPO_4) and 5 parts N (NH_4HCO_3) per 100,000. B: Filter fed with a solution of 100 parts of sucrose, 3 parts P_2O_5 (K_2HPO_4) and 0.5 part N (NH_4HCO_3) per 100,000. C: General trend of Curve B.

resulted in removal of nitrogen such continuous sampling was not carried out in this experiment. However, in a later experiment made at Colwick, Nottingham (see Exp. 3), analyses were made at regular periods on the effluents of two filters, which received the same nutrient solution and produced consistently similar effluents. The only difference between these two filters was that one was inoculated by Mr Cutler and Miss Crump of Rothamsted with selected organisms, while this treatment was omitted from the other filter. The results of these analyses are shown in Table V.

These figures show that over a period of several hours the maximum variation of the composition of the effluent from the mean value as measured by the "4 hours" and sugar analyses was less than 10%: the p_H of the effluents varied only slightly. It is probable that the results of analysis with a laboratory filter fed with a solution of constant composition and at a steady rate of flow

Table V.

Time of sampling p.m.	P_H		Parts per 100,000			
	Inocu- lated filter	Uninocu- lated filter	"4 hours"*		Sugar	
			Inocu- lated	Uninocu- lated	Inocu- lated	Uninocu- lated
12.01-12.04	6.9	6.7	31.9	32.0	10.7	10.3
12.04-12.09	6.8	6.6	31.5	33.8	12.1	11.4
12.09-12.15	6.8	6.5	33.7	34.7	11.3	12.4
12.15-12.20	6.8	6.5	32.7	34.3	11.3	11.3
12.20-12.25	6.9	6.4	30.4	35.9	11.6	11.6
12.25-12.30	6.8	6.5	30.8	36.3	10.6	10.9
12.30-12.35	6.8	6.5	30.8	33.0	11.9	11.7
12.42-12.52	6.8	6.4	30.2	33.8	11.0	11.1
4.0	6.8	6.4	31.1	33.4	11.3	11.9
6.0	6.7	6.3	34.3	34.9	9.4	12.1

* The "4 hours" figure is a measure of the organic matter oxidisable by permanganate.

would show even smaller oscillations than those obtained with a semi-commercial plant.

The daily fluctuation in the amount of sugar oxidised in Exps. 2 B and 3 may have its counterpart in the day to day variation in bacterial numbers. Thornton and Gray [1930] showed that the numbers of bacteria in soil rarely remain static but oscillate between wide intervals in short periods. Sandon and Dixon [unpublished work] have found similar changes in the numbers of bacteria, fungi and protozoa in percolating filters, while the numbers of *Staphylococcus aureus* in meat juices were found to fluctuate over a period of 44 days [Foreman and Graham Smith, 1928]. At this stage of the experiments any explanation of the fluctuation in the actual performance of the nitrogen-starved filter can only be regarded as tentative. It is suggested that a peak in the graph represents a condition in the filter when all the incoming nitrogen, whether in the form of ammonia or as nitrogen liberated by bacterial autolysis is being used for microbial development. A large proportion of the dissolved sugar is then required by the organisms and the amount of sugar oxidised is correspondingly great. The slope from a peak down to a trough is assumed to be caused by unfavourable growth conditions in which only part of the ammoniacal form and none of the organic form of nitrogen is utilised, so that less sugar is needed by the population of the filter. Cutler *et al.* [1922] have shown that an inverse ratio exists between the numbers of bacteria and protozoa in soil, bacteria being abundant when protozoa are few. When sufficient available food material is supplied to a mixed flora such as exists in soil or in a filter, interdependent variations in the numbers of organisms may occur without any alteration in the rate of oxidation of foodstuff. With a large excess of nutrient substance, however, biological variations might conceivably affect the rate of oxidation of the food substance.

The losses of water by evaporation in Exp. 2 were less than 1% (Tables VI and X) and confirm the small loss recorded in Exp. 1. The figures for nitrogen given in Table VII show that in the filter receiving a solution with a C:N ratio of 8.4:1, 12.8% of the nitrogen disappeared. With the larger ratio of 84:1 however a small gain of 0.057 g. or 5.7% of the nitrogen supplied was recorded (Table XI). The difference between duplicate analyses of total nitrogen by the Kjeldahl method was of the order of 0.15 cc. N/15 acid with 250 cc. effluent. Assuming that this difference always operated in one direction, recording, say, a greater amount in the solutions than was actually present, then a gain of less

Table VI. *Filter A. C:N ratio 8:4:1.*
Volume balance sheet (Exp. 2).

Period days	Volume filtered cc.	Volume recovered as effluent cc.	Volume retained by filter <i>plus</i> vol. lost by evaporation cc.
0-7	12,748	12,608	140
8-14	12,568	12,435	133
15-21	13,062	12,998	64
22-28	22,927	22,544	383
29-35	25,382	25,153	229
36-42	25,067	24,773	294
43-51	25,004	24,303	701
52-58	16,399	16,436	-37
Total	153,157	151,250	1907

Liquid in filter = 667
Loss by evaporation = 1240 = 0.8 %

Table VII. *Filter A. C:N ratio 8:4:1.*
Nitrogen balance sheet (Exp. 2).

Period days	Nitrogen added as NH_4HCO_3 g.	Nitrogen recovered in effluent, g.			Section No.	Nitrogen recovered in film, g.		
		Total N	NH_3 - N	Organic N		Total N	NH_3 - N	Organic N
0-7	0.6304	0.3047	0.0145	0.2902	1	1.0135	0.1464	0.8671
8-14	0.6218	0.5054	0.3396	0.1658	2	0.5064	0.1344	0.3720
15-21	0.6499	0.4550	0.3397	0.1153	3	0.2639	0.1033	0.1606
22-28	1.1222	0.5629	0.4653	0.0976	4	0.1578	0.1062	0.0516
29-35	1.2577	0.5582	0.4745	0.0828	Total	1.9416	0.4903	1.4513
36-42	1.2387	0.5974	0.4350	0.1624				
43-51	1.2152	0.9361	0.5745	0.3616				
52-58	0.8218	0.7305	0.4035	0.3270				
Total	7.5577	4.6502	3.0475	1.6027				

Nitrogen recovered = $4.6502 + 1.9416 = 6.5918$ g.
Nitrogen unaccounted for = $7.5577 - 6.5918 = 0.9659$ g. = 12.8 %

than 0.041 g. nitrogen would not be significant. The increase with Filter B was 0.057 g., indicating some fixation of atmospheric nitrogen.

Christensen and Fulmer [1927] have shown that the nitrogen in yeast is not recovered quantitatively by the ordinary Kjeldahl method and that 15% of the nitrogen may be lost unless precautions are first taken to break down the cyclic nitrogen compounds which are believed to be the source of the low results. In view of the losses of nitrogen in the experiments already described determinations of nitrogen in the film were made by the usual Kjeldahl method and by the modified Kjeldahl method of Christensen and Fulmer [1927] which involved preliminary oxidation of the material with hydrogen peroxide and sulphuric acid. The nitrogen in 100 cc. samples of a suspension of film from the first section of Filter A was found by evaporating the solution to dryness and carrying out the analysis by the two methods. The volumes of $N/10$ HCl neutralised in the Kjeldahl determinations were 15.2, 14.75, and 14.95 cc.; average 14.97; in the Christensen and Fulmer method the figures were 14.8, 15.1, and 14.9; average 14.93, showing that the nitrogen in the film is recovered as completely by the ordinary Kjeldahl method as by the peroxide modification.

The amounts of phosphorus and potassium recovered (Tables VIII, IX, XII and XIII) while greater in proportion than those in Exp. 1, were less than the

amounts supplied. The amounts of C, N, P_2O_5 and K_2O in the biological films of the two filters were:

Amount of C, N, P_2O_5 and K_2O in 100 g. of dry film.

	C:N 8.4:1	C:N 84:1
	g.	g.
C	46.2	46.2
N	7.0	3.5
P_2O_5	2.54	4.83
K_2O	1.18	3.38

Table VIII. *Filter A. C:N ratio 8.4:1.*
Potash balance sheet (Exp. 2).

Period days	K_2O added in nutrient solution g.	K_2O recovered in effluent g.	Section No.	K_2O recovered in film g.
0-7	0.5071	0.2823	1	0.1501
8-14	0.5001	0.5429	2	0.0508
15-21	0.5198	0.4710	3	0.0367
22-28	0.9122	0.7253	4	0.0089
29-35	1.0101	1.0185	Total	0.2465
36-42	0.9976	0.9571		
43-51	0.9952	1.0452		
52-58	0.6525	0.5745		
Total	6.0946	5.6168		

K_2O recovered = $5.6168 + 0.2465 = 5.8633$ g.
 K_2O unaccounted for = $6.0946 - 5.8633 = 0.2313$ g.

Table IX. *Filter A. C:N ratio 8.4:1.*
Phosphorus balance sheet (Exp. 2).

Period days	P_2O_5 added in nutrient solution g.	P_2O_5 recovered in effluent g.	Section No.	P_2O_5 recovered in film g.
0-7	0.3824	0.2256	1	0.2424
8-14	0.3770	0.3362	2	0.1521
15-21	0.3919	0.2900	3	0.0787
22-28	0.6878	0.3526	4	0.0548
29-35	0.7815	0.3272	Total	0.5280
36-42	0.7502	0.3633		
43-51	0.7501	0.6230		
52-58	0.4920	0.4276		
Total	4.6129	2.9455		

P_2O_5 recovered = $2.9455 + 0.5280 = 3.4735$ g.
 P_2O_5 unaccounted for = $4.6129 - 3.4735 = 1.1394$ g.

Table X. *Filter B. C:N ratio 84:1.*
Volume balance sheet (Exp. 2).

Period days	Volume filtered cc.	Volume recovered as effluent cc.	Volume retained by filter plus vol. lost by evaporation cc.
0-7	12,927	12,775	152
8-14	13,028	12,852	176
15-21	12,968	12,796	172
22-28	21,978	21,562	416
29-35	25,311	25,172	138
36-42	25,443	25,351	92
43-51	24,153	23,885	268
52-58	21,775	21,688	87
59-65	24,245	23,895	350
66-70	17,445	17,425	20
Total	199,273	197,402	1871

Water in filter = 445

Loss by evaporation = $1871 - 445 = 1426 = 0.7\%$ of volume filtered

Exp. 3. In a large-scale experiment carried out at the beet-sugar factory at Colwick in order to test the value of inoculating a percolating filter with selected organisms, two adjacent filters were used. Each filter was 6 ft. deep and contained 2 cu. yd. of graded gravel. Effluent from the factory was treated on these filters, one of which was inoculated at intervals with certain selected organisms while the other filter, which was not inoculated, served as a control. The factory effluent differed from the liquids filtered in the laboratory experiments but for

Table XI. *Filter B. C:N ratio 84:1.*
Nitrogen balance sheet (Exp. 2).

Period days	Nitrogen added as NH_4HCO_3 g.	Nitrogen recovered in effluent, g.			Section No.	Nitrogen recovered in film, g.		
		Total N	NH_3 - N	Organic N		Total N	NH_3 - N	Organic N
0-7	0.0646	0.0525	0.0155	0.0370	1	0.3343	0.0288	0.3055
8-14	0.0651	0.0230	0.0033	0.0197	2	0.1064	0.0096	0.0968
15-21	0.0648	0.0292	0.0027	0.0265	3 }	0.0620	0.0000	0.0620
22-28	0.1099	0.0356	0.0000	0.0356	4 }			
29-35	0.1266	0.0602	0.0000	0.0602	Total	0.5027	0.0384	0.4643
36-42	0.1272	0.0492	0.0048	0.0444				
43-51	0.1208	0.0537	0.0000	0.0537				
52-58	0.1089	0.0711	0.0000	0.0711				
59-65	0.1212	0.0991	0.0554	0.0437				
66-70	0.0872	0.0770	0.0214	0.0556				
Total	0.9963	0.5506	0.1031	0.4475				

Nitrogen recovered = $0.5506 + 0.5027 = 1.0533$ g.

Gain in nitrogen = $1.0533 - 0.9963 = 0.0570$ g. = 5.7 %

Table XII. *Filter B. C:N ratio 84:1.*
Potash balance sheet (Exp. 2).

Period days	K_2O added in nutrient solution g.	K_2O recovered in effluent g.	Section No.	K_2O recovered in film g.
0-7	0.5143	0.5000	1	0.2585
8-14	0.5183	0.4619	2	0.1402
15-21	0.5160	0.3936	3 and 4	0.0893
22-28	0.8745	0.6581	Total	0.4880
29-35	1.0072	0.8420		
36-42	1.0127	0.7452		
43-51	0.9611	0.9204		
52-58	0.8664	0.8193		
59-65	0.9648	0.9350		
66-70	0.6942	0.5255		
Total	7.9295	6.8010		

K_2O recovered = $6.8010 + 0.4880 = 7.2890$ g.

K_2O unaccounted for = $7.9295 - 7.2890 = 0.6405$ g.

the purpose of the present paper its chief interest lies in the fact that it contained nitrogen in organic combination and only a negligible amount of ammoniacal nitrogen. During the first 9 days of the experiment (Oct. 21st-29th, 1931), only one set of samples was collected and analysed. During the remaining period of the experiment, Oct. 30th, 1931 to Jan. 4th, 1932, representative samples of the crude liquor pumped to the supply tank for the filters and of the treated effluents were collected each day. The results of nitrogen determinations in these samples and in the biological film collected from the media of the filters at the end of the experiment are given in Table XIV. From the nitrogen balance sheet also given in Table XIV, it appears that the total amounts of

nitrogen recovered in the effluents and in the films were 21 to 24 % less than in the untreated liquid.

Table XIII. *Filter B. C:N ratio 84:1.*
Phosphorus balance sheet (Exp. 2).

Period days	P ₂ O ₅ added in nutrient solution g.	P ₂ O ₅ recovered in effluent g.	Section No.	P ₂ O ₅ recovered in film g.
0-7	0.3878	0.3371	1	0.3535
8-14	0.3908	0.3830	2	0.1744
15-21	0.3890	0.3268	3 and 4	0.1124
22-28	0.6593	0.5435	Total	0.6403
29-35	0.7593	0.6131		
36-42	0.7633	0.5948		
43-51	0.7246	0.5545		
52-58	0.6533	0.4841		
59-65	0.7274	0.5372		
66-70	0.5234	0.4372		
Total	5.9782	4.8114		

P₂O₅ recovered = 4.8114 + 0.6403 = 5.4517 g.
P₂O₅ unaccounted for = 5.9782 - 5.4517 = 0.5265 g.

Table XIV. *Nitrogen balance sheet of large-scale percolating filters (Exp. 3).*

Date 1931	Volume crude liquor filtered gallons	Total N in crude liquor	Total N in effluent from inocu- lated filter	Total N in effluent from uninocu- lated filter	Total N supplied by crude liquor to each filter in lbs.	Total N in lbs. recovered in	
			Parts per 100,000			Inocu- lated filter effluent	Uninocu- lated filter effluent
Oct. 21-29	329	4.850	3.472	3.774	0.1596	0.1142	0.1242
„ 30	50	5.476	1.490	1.490	0.0274	0.0075	0.0075
„ 31	50	5.376	1.030	1.030	0.0269	0.0052	0.0052
Nov. 1	30	4.603	0.784	0.784	0.0138	0.0023	0.0023
„ 2	50	6.260	1.378	1.288	0.0313	0.0069	0.0064
„ 3	100	4.839	1.568	1.523	0.0484	0.0157	0.0152
„ 4	100	4.245	1.187	1.299	0.0425	0.0119	0.0130
„ 5	100	3.158	1.255	1.277	0.0316	0.0126	0.0128
„ 6	100	3.069	1.143	1.120	0.0307	0.0114	0.0112
„ 7	200	3.147	0.829	0.974	0.0629	0.0166	0.0195
„ 8	200	3.584	0.986	1.030	0.0717	0.0197	0.0206
„ 9	200	2.878	1.064	1.098	0.0576	0.0213	0.0213
„ 10-14	1000	3.181	1.109	1.109	0.3181	0.1109	0.1109
„ 15-19	1100	2.890	1.154	1.288	0.3179	0.1269	0.1417
„ 20-23	1000	1.613	0.851	0.851	0.1613	0.0851	0.0851
„ 24-28	1250	1.915	0.918	0.918	0.2393	0.1147	0.1147
„ 29-Dec. 3	1250	2.117	1.019	0.907	0.2646	0.1274	0.1134
Dec. 4-8	1250	3.819	1.456	1.345	0.4773	0.1820	0.1681
„ 9-13	1250	2.800	1.512	1.501	0.3500	0.1890	0.1876
„ 14-18	1250	2.710	1.456 (?)	1.456	0.3387	0.1820	0.1820
„ 19-24	1500	2.128	1.546	1.725	0.3192	0.2319	0.2587
„ 30-Jan 4, 1932	900	3.342	1.997	3.062	0.3008	0.1797	0.2759
Total					3.6916	1.7749	1.8973
Summary			Inoculated filter			Uninoculated filter	
Total nitrogen added, lbs.			3.6916			3.6916	
Nitrogen recovered: (a) in effluent			1.7749		1.8973		
(b) in film			1.0420		2.8169	2.9053	
Total N lost			0.8747 = 23.7 %			0.7863 = 21.3 %	

The conditions of experiment with these large filters at the factory could not be so definitely controlled as with the smaller laboratory filters. At the factory the acidity of the crude liquor increased during the 24 hours for which it was stored. As the acidity increased solid matter was precipitated and only a portion of this passed on to the filter; part was lost whenever the supply tanks were cleaned out. It is probable therefore that the true losses of nitrogen were really less than the amounts indicated in Table XIV.

DISCUSSION OF RESULTS.

Loss of nitrogen in biological reactions has frequently been supposed [Waksman, 1931, p. 481] to result from the reduction of nitrites or nitrates to gaseous nitrogen. In order to determine the extent of this type of reduction Muntz and Lainé [1911] filtered through soil crude sewage to which nitrate had been added. In a previous paper [Jenkins, 1933, 2] the author gave the results of experiments in which solutions of sugar and nitrite, sugar and nitrate and sugar and ammonium chloride were treated in biological filters, and these results showed that large proportions of the nitrogen present in the original solutions were not recovered in the effluents. Barritt [1931, 2] has shown that the reaction between nitrate and amino-acid in a biological environment results in loss of elementary nitrogen from the nitrate, the amino-acid remaining intact above p_H 6.0. Another explanation of loss of nitrogen from soil which Waksman [1931, p. 484] considers possible is the interaction of ammonia and nitrous acid, with the production of free nitrogen. In a study of the biochemistry of water-logged soils Subrahmanyam [1917] concluded that organic nitrogenous compounds were decomposed in water-logged soils and that ammonia was split off, the losses of nitrogen which may occur in such soils are, according to this author, due to the volatilisation of ammonia and not to the liberation of the free element. Davy [1814] concluded that nitrogen was lost from manure by fermentation and suggested that the formation of ammonia was an intermediate stage of the reaction. The author indicated in a previous paper [Jenkins, 1933, 2] that considerable amounts of nitrogen were unaccounted for when nitrogen was supplied to a percolating filter as nitrite, nitrate or ammonia. It is a well established fact that nitrites and nitrates can supply oxygen to certain organisms provided anaerobic conditions are maintained. It is equally well established that when anaerobic conditions exist in a percolating filter nitrification does not take place. Again, in order that volatilisation of ammonia may occur, as was suggested by Subrahmanyam [1917], the p_H of the medium must be above 7.0. Now in the laboratory tests described in Exps. 1 and 2, the initial p_H of the nutrient solution was 6.0 and the p_H of the final effluent in the first experiment was 3.0 for more than half the experimental period. As was previously stated the reduction in p_H of the solution from 6.0 to 3.0 was caused by the liberation of mineral acid from ammonium chloride, owing to the uptake of ammonia from the ammonium chloride supplied: in the second experiment the source of nitrogen was ammonium bicarbonate and the filtrate had the same p_H as the nutrient solution, *viz.* 6.0. The filters in the second experiment never produced nitrite or nitrate, although they did not choke and become anaerobic. The formation of nitrite and nitrate evidently requires a prolonged time of passage through the filter or a time of contact with the medium which the tubular glass filling used for the experiments does not provide. Hence it seems that neither nitrification followed by subsequent liberation of free nitrogen, nor volatilisation of ammonia from the surface of the media accounts for the loss of nitrogen found in the experiments in which

a C:N ratio of 8.4:1 was maintained. A suggestion has been made by Waksman [1931, p. 484] that nitrogen gas is produced from organic compounds through biological agencies. The course of the decomposition according to this writer is first the formation of ammonia, which then undergoes biological oxidation to nitrogen either by oxygen or hydrogen peroxide. If there were any extensive ammonification of organic compounds in a percolating filter it is likely that some indication of its occurrence would be shown by the appearance of ammonia, particularly when conditions in the film did not favour ammonia oxidation. The losses of nitrogen in Exp. 3 amounted to an average of 22.5 % for the two filters calculated on the total nitrogen supplied. The nitrogen in the crude liquor consisted mainly of protein though some betaine and other organic sources of nitrogen were no doubt present. Although the nutrient liquid fed to the filters contained traces of ammoniacal nitrogen, i.e. about 0.1 part N per 100,000, the concentration of nitrogen as ammonia in the effluents never exceeded, and was generally less than, this figure. Moreover, nitrite as measured by *metaphenylenediamine* was only found in traces on one day out of the 76 days of the experiment. Consideration of the results of this last experiment point to an appreciable loss of nitrogen from organic matter submitted to biological filtration. According to evidence put forward in this paper, the loss appears to be caused by the direct liberation of free nitrogen, without the intermediate formation of ammonia or nitrite or nitrate. This of course does not preclude the occurrence of such intermediate reactions within the cells of the organisms responsible for the liberation of nitrogen. The question therefore arises: Is there any evidence which might point to the existence of organisms in percolating filters or soils which are able to effect the breakdown of organic nitrogenous compounds directly to gaseous nitrogen? A search of the literature on this subject has revealed only one reference to an organism of this nature. Wood and Wilcox [1897] claimed to have isolated an organism able to liberate free nitrogen directly from organic matter. Their work has not as yet been confirmed. It has been shown in this paper that ammonium compounds undergo decomposition in percolating filters with loss of nitrogen, such loss being influenced largely by the C:N ratio of the solutions filtered. Losses of nitrogen from solutions containing ammonia were recorded when this ratio was 8.4:1 while with organic sources of nitrogen (Exp. 3) the C:N ratio was of the order of 20:1. If the ratio is increased to 84:1 the recovery of nitrogen is quantitative and there is also a slight but significant gain due possibly to the fixation of atmospheric nitrogen.

The quantitative relationship between the amount of carbohydrate oxidised and the nitrogen used in the oxidation (assumed to be the difference between the nitrogen supplied and the ammoniacal nitrogen recovered in the film and in the effluents) will be seen from Table XV to differ considerably in the two filters.

It is evident from these results that to obtain complete oxidation of sugar by biological filtration carbon and nitrogen must be present in solution in a ratio not exceeding 62:1, since these elements are removed in this ratio when a limited amount of nitrogen and excess of sugar are filtered. With a C:N ratio of 62:1 the most effective use is made of the nitrogen supplied, but in order (a) to ensure sufficient nitrogen to build up an efficient film, (b) to obtain complete decomposition of sugar and (c) to allow for losses of nitrogen washed out of the filter as organic matter, a smaller ratio than 62:1 is required. Although carbon and nitrogen were supplied in the ratio of 8.4:1 in Filter A these elements were removed in the ratio of 15.4:1 so that a large wastage of nitrogen occurred. It follows therefore that complete oxidation of sugar and most effective use of

nitrogen are obtained when the C:N ratio lies between 15.4:1 and 62:1: a ratio of the order of 30:1 would probably satisfy these conditions.

The quantities of nitrogen assimilated in the combustion of 100 g. of sugar in Filters A and B are given in column 8. These figures are of interest in the light of experiments made by Hutchinson and Richards [1921] in which it was observed that when straws were decomposed by micro-organisms a definite relationship existed between the amount of carbohydrate decomposed and the amount of nitrogen immobilised. Later the term "nitrogen factor" was introduced to define the quantity of added nitrogen immobilised in decomposing 100 g. of straw, and Richards and Norman [1931] showed that this factor varied considerably in plant materials of different origin, that of flax straw being 0.46 and of oat straw 0.8. If these experiments are to be compared with those obtained by the decomposition of straw in heaps, the differences between the two methods should be recognised. The nitrogen not immediately used in a percolating filter passes out of the filter and is lost whereas in straw decompositions nitrogen in the inorganic form is available for microbial requirements. Moreover, the carbohydrate decomposed in the experiments described in this paper was pure and in solution while Richards and Norman [1931] used mixtures of solid polysaccharides. It is of interest to note that whereas the nitrogen factor of a given plant material remains approximately the same whether sufficient or excess of nitrogen is supplied, with a carbohydrate solution undergoing biological filtration the factor varies according to the C:N ratio used.

The amounts of carbon oxidised and carbon fixed as film are given in Table XV. The figures show that the quantities of carbon recovered as film in Filters A and B for every 100 g. of carbon oxidised were 16 g. and 11.5 g. respectively.

Table XV. *Amount of sugar oxidised and nitrogen used, in g., in Filters A and B.*

	Col. 1 Sucrose added	Col. 2 Sucrose recovered in effluent	Col. 3 Sucrose oxidised Col. 1 - Col. 2	Col. 4 Nitrogen ad'ded	Col. 5 Nitrogen recovered as NH_3 in effluent	Col. 6 Nitrogen recovered as NH_3 in film
Filter A. C:N=8.4:1. Operated for 58 days	153	6	147	7.558	3.048	0.490
Filter B. C:N=84:1. Operated for 70 days	200	74	126	0.996	0.103	0.038
	Col. 7 Nitrogen used Col. 4 - Col. 5 - Col. 6	Col. 8 Ratio: Sucrose oxidised Nitrogen used	Col. 9 Ratio: Carbon oxidised Nitrogen used	Col. 10 Carbon oxidised	Col. 11 Carbon in film on filter	
Filter A. C:N=8.4:1. Operated for 58 days	4.020	100 2.73	15.4 1	61.9	9.9	
Filter B. C:N=84:1. Operated for 70 days	0.855	100 0.68	62.1 1	53.1	6.1	

SUMMARY.

1. A study has been made of the decomposition of sucrose in the presence of inorganic salts of nitrogen, phosphorus and potassium by the method of biological filtration. Glass percolating filters, allowing for the recovery of organic film, were used to draw up balance sheets for the volume of liquid filtered and

the amounts of nitrogen, phosphorus and potassium added. The recovery of the last two elements was not quantitative, possibly owing to inadequate methods of analysis. The losses of water due to evaporation were 1.8 % in one experiment which lasted for 108 days; losses of 0.8 % and 0.7 % were found in filters which were operated for 58 and 70 days respectively.

2. In two experiments the solutions filtered contained sugar and ammonium salts sufficient to provide C:N ratios of 8.4:1 and in the third the ratio was 84:1. The balance sheets for nitrogen showed that 14 and 13 % of the total nitrogen supplied was lost in the case of the first two filters while a slight gain, equal to 5.7 % was recorded with the third filter.

3. Two large-scale filters were fed for 76 days with beet-sugar factory effluents. These effluents contained sugar and organic acids derived from sugar, and nitrogen in the form of organic compounds. The losses of total nitrogen were 24 and 21 % of the amount supplied, but these figures include some nitrogen lost in cleaning out the tanks used for storing the factory effluents. The C:N ratio of the solutions filtered was approximately 20:1.

4. When filters were supplied with an ammonium salt as the source of nitrogen, neither nitrite nor nitrate was detected in the effluents. There is thus no evidence for assuming that where nitrogen was lost from the filters nitrite or nitrate occurred as an intermediate compound. When the source of nitrogen supplied to the filters was organic, neither ammonia nor oxidised compounds of nitrogen were found. Consequently it cannot be maintained that the losses of nitrogen from these filters arose from the formation of ammonia or the production of nitrite or nitrate and subsequent denitrification. It appears, therefore, that the liberation of nitrogen from ammonia and organic compounds of nitrogen may be carried out entirely within the cell of an organism.

5. For every 100 g. of carbon as sugar oxidised, the amounts of carbon fixed in the filters as film were 16 g. and 11.5 g. when the C:N ratios of the nutrient solutions were 8.4:1 and 84:1 respectively.

These experiments were carried out as part of the programme of the Water Pollution Research Board of the Department of Scientific and Industrial Research and the results are published by permission of the Department. The author wishes to record his thanks to Mr E. H. Richards, Head of the Fermentation Department at Rothamsted, for advice and criticism throughout this work, to Mr S. J. Roberts of the Birmingham Tame and Rea Drainage Board for valuable assistance in the experiments carried out at Colwick, and to the staff of the Anglo-Scottish Beet-Sugar Corporation, Ltd., Colwick, Notts. for kindly co-operation during part of this work. His thanks are also due to Mr D. W. Cutler, Head of the Microbiology Department and his staff for permission to refer to their unpublished results.

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DASYNEURA LEGUMINICOLA (LINT.)
THE CLOVER SEED MIDGE

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(With Plate XV and 2 Text-figures.)

CONTENTS.

	PAGE
I. Introduction	185
II. Methods	186
III. Identification	186
IV. Life history	188
V. Damage and attack	192
VI. Control	194
VII. Summary	202
VIII. Acknowledgments	203
References	203
Explanation of Plate	204

I. INTRODUCTION.

THE first definite records of the clover seed midge come from America, where Lintner observed the larvae in the heads of red clover in 1877. The midge was described by him as *Cecidomyia trifolii* sp.n. in 1879, but later in the same year he changed the name to *C. leguminicola*. In the *Report on Injurious Insects* 1890, Ormerod (1891) mentions the American clover seed midge, which she states "has only lately appeared in this country—but still we cannot tell with certainty how long it has been here." She goes on to describe the anchor process of the larva, a character distinguishing it from the larvae of *Amblyspatha ormerodi*, another midge found on clover, and there is no doubt that she was actually dealing with *Cecidomyia leguminicola*. The name was again changed, this time by Aldrich in 1905, to *Dasyneura leguminicola*. The midge has also been recorded in Denmark (Schøyen, 1927) and in Wales (Jenkins, 1926).

In 1918 a paper was published by Rockwood and Creel on its control. Barnes (1927) gives a useful summary of the literature to date, and since then Wehrle's paper (1929) dealing with the life history and methods of control has appeared. Apart from Ormerod's notes, the life history of the

clover seed midge, the damage done by the larvae, and the methods of control have not been studied in Great Britain. It is hoped that the following paper will repair this omission. The work was carried out at Harpenden from February, 1931 to July, 1932.

II. METHODS.

In order to secure a supply of adults for the purpose of experimentation, over-wintering cocoons of *D. leguminicola* were washed out of the soil adhering to the roots of clover plants brought in from the field in March, 1931. They float on the surface of the water and are easily picked out. They were then placed on damp coconut fibre in jam jars and kept moist.

Material for the second brood was obtained by gathering infested heads of clover from Long Hoos Field, Rothamsted Experimental Station, towards the end of June, when most of the larvae were ready to pupate, but had not left the flower heads. These were placed on damp coconut fibre enclosed by a lamp glass and covered by a circle of muslin sewn to an iron ring. The heads were watered at intervals. Material for the spring brood of 1932 was kept over winter in the same way. In each case a record of the daily emergence of midges and parasites was kept throughout the hatching period.

For the cross-mating experiments, immunity trials, and life-history observations, clover plants growing in pots were covered with muslin bags before the flower heads appeared. Midges were introduced when the heads were at the green stage, and the heads examined for eggs and larvae at suitable intervals. When the larvae were full grown, the heads were cut and sprayed with water at intervals, the larvae which dropped out being placed on sand or damp fibre for pupation.

III. IDENTIFICATION.

Two midges of the genus *Dasyneura*, viz. *D. leguminicola* Lint. and *D. flosculorum* Kieff. (1890), are reported to prevent the formation of seed in red clover. The former is the midge found in America, the latter is recorded from Central Europe (Liebel, 1889; Schlechtendal, 1890), Sweden (Tullgren, 1917), and Great Britain (Bagnall and Harrison, 1918). Kieffer's description of *D. flosculorum* might well be applied to *D. leguminicola*, and for the purpose of distinguishing between the species it was decided to attempt mating experiments. Samples of clover heads infested with *D. leguminicola* had been obtained by Dr H. F. Barnes¹

¹ Dr Barnes very kindly handed over this material and also his MS. notes on this midge when I took over this work on my arrival at Rothamsted in February, 1931.

from Ottawa and Ithaca, in September, 1930. These were kept over winter in coconut fibre in the usual manner. Application was made to Sweden for similar samples of heads with *D. flosculorum*, but proved unsuccessful, and no material was received.

The adults of *D. leguminicola* which hatched in May and June, 1931, were crossed with midges bred from clover in Harpenden. The crosses were successful, mating took place willingly and eggs were laid in every case. In the cross Canadian ♀ × English ♂, adults which appeared to be quite normal were bred through. In other cases larvae were obtained and kept for examination, no attempt being made to rear the adult. The larvae appeared to be normal.

From these experiments, it appears that the clover seed midge present in England is *D. leguminicola* Lint. It still remains to be proved that this is the midge known in Central Europe and Sweden under the name of *D. flosculorum*. *D. leguminicola* bred from English larvae in 1930–2 agrees with Lintner's somewhat meagre description of *Cecidomyia leguminicola*. This has been amplified, and a new description appears below.

DASYNEURA LEGUMINICOLA LINT.

Male. Body length, 1.5–2 mm. Antennae: of typical *Dasyneura* structure; fuscous brown; ranging from 2 + 12 to 2 + 16, the maximum number of individuals having 2 + 14; node of eighth flagellar segment about equal to the neck, about half as long again as broad, slightly constricted towards the middle; neck of third flagellar segment five-sixths of node; terminal node rather longer than preceding, conical; nodes with a regular basal whorl of short setae about half length of the node, a distal irregular whorl of longer setae reaching to about the middle of the succeeding node, and irregular long setae about three times the length of the node. Palps: sparsely haired, pale yellow; 1st and 2nd segments of equal length, 3rd half as long again, distal twice as long as the 2nd; 3rd and distal segments narrower than 1st and 2nd, tapering to the tip. Face: yellow. Eyes: black. Thorax: dorsal region, scutellum, post-scutellum and pleurae dark fuscous, rest of thorax yellow. Wings: hyaline: veins distinctly scaled. Abdomen: deep orange, sterna with anterior and posterior bands of fuscous brown, terga and pleura fuscous brown with patches of dark scales. Legs: pale yellow clothed with dark fuscous scales; claws curved at right angles; empodium slightly longer or same length as claws. Genitalia: basal clasp segment stout with long stout setae; terminal clasp segment curved, stout, with short setae;

188 *D. leguminicola* (Lint.), the Clover Seed Midge

dorsal plate deeply emarginate, the lobes rounded; ventral plate deeply or shallowly emarginate, variable, the lobes narrowly rounded; harpes well developed, digitiform apically; style about the same length or a little longer than the ventral plate.

Described from Cecid. 1864-7 deposited in the Barnes collection.

Female. Body length: rather longer and more robust than in the male. Antennae: of typical *Dasyneura* structure; fuscous brown; ranging from 2 + 12 to 2 + 16 with the greatest number of individuals with 2 + 14; neck of 3rd flagellar segment transverse; segments furnished as in the male with two regular whorls, and irregular scattered setae, shorter than in the male. Palps: light red, 1st segment as long as broad, rather shorter than 2nd segment; 3rd segment about twice as long as basal; terminal segment about twice as long as 2nd. Abdomen: deep red to orange, darker than in the male, intersegmental membranes light, dorsal region with conspicuous bands of dark scales. Ovipositor: pocket type; about twice as long as the body when extended. Otherwise about as in male.

Described from Cecid. 1868-72 deposited in the Barnes collection.

IV. LIFE HISTORY.

According to Wehrle, the clover seed midge is typically two-brooded in the neighbourhood of Ithaca, N.Y., the first brood being on the wing in the early part of June, and the second brood appearing in August and September.

At Harpenden in 1930, the emergence of the first brood started on May 17th and lasted until July 17th, with the crest of emergence on May 30th; in 1931 the first brood hatched between May 27th and June 15th, with the maximum hatch on May 30th and 31st; and in 1932 from May 23rd to June 29th, with the maximum on June 3rd. The second brood in 1931 was on the wing between July 14th and September 19th, with the crest of emergence on August 3rd. In 1932 the first emergences of second brood were on July 15th. In the 1930 first brood the sex ratio was 46 : 54, 1297 males and 1526 females being reared; in the 1931 first brood 65 males and 65 females gave a sex ratio of 50 : 50, and second brood 318 males and 456 females gave a sex ratio of 41 : 59; in 1932 the sex ratio of the 1st brood was 35 : 65, 664 males and 1212 females being reared. The males emerge rather before the females: the dates of the comparative crests of emergence for the two sexes being in 1930 (first brood): males May 28th, females May 30th; 1931 (first brood) males May 28th, females May 30th, (second brood) males August 3rd, females August 5th; and in

1932, 1st brood males and females June 3rd. The greatest number of the midges appears before 11 a.m. (standard time), the males emerging slightly before the females. The emergence of both sexes then gradually falls off, and ceases soon after 7 p.m.

A. Oviposition.

Mating is effected soon after emergence, and oviposition may take place from 3 hours to 2 days after mating. The clover flowers selected by the females are in the green-head stage (see Plate XV, A), with very little colour of the flower showing. The ovipositor is thrust down between the florets and the eggs are deposited among the hairs on the calyx singly, or in groups of from two to five. The egg is smooth and shiny, pale yellow in colour and slightly broader at one end than the other.

B. Egg stage.

The length of the egg stage varies from 2 to 6 days. In 1931, females were observed ovipositing on flower heads on June 6th. Newly hatched larvae and eggs containing segmented larvae were found on these flower heads on June 8th, other newly hatched larvae on June 10th. In 1932, ovipositing females were seen on May 30th, eggs were found on May 31st, and newly hatched larvae from June 4th to 6th. The average measurement of the eggs in 1931 was 0.290×0.056 mm., in 1932 it was 0.295×0.060 mm. This is rather smaller than the average given by Wehrle (1929) which was 0.3139×0.0849 mm. in 1921, and 0.3240×0.0790 mm. in 1922.

C. The first stage larva.

Wehrle does not state the number of ecdyses passed through by *D. leguminicola*, and, indeed, Hamilton (1925) is the only investigator who has arrived at any definite conclusion regarding the number of larval instars in the Cecidomyiidae. He states that *Monarthropalpus buxi* has four. Kieffer (1900) and Marchal (1897) both say that the larva passes through three phases, each of which may comprise one or more instars.

There appear to be at least four instars, distinguished from each other by definite morphological characters, in *D. leguminicola* Lint. A full account of the morphology will shortly be published.

The first instar larvae which emerge from the egg may be found on the outside of the calyx. They are small, delicate and quite transparent, measuring about 0.350×0.08 mm. Thirteen segments, including the head, are present, but the supernumerary segment or neck is not very noticeable. Antennae, mouth-parts, and eyespots are well developed. The cuticle is quite transparent and there is no sternal spatula. Only the

190 *D. leguminicola* (*Lint.*), the Clover Seed Midge

terminal spiracles are present and these are very prominent. The head appears much better proportioned to the body in this instar than in the subsequent ones. Entrance into the floret appears to be effected simply by eating a way through. Tiny holes in the calyx and corolla have been found which point to this method of entrance. The duration of the first instar has not been determined accurately, but cannot be more than about 2-4 days. In the case of eggs laid on May 31st, the first instar larvae were found on June 4th and the third instar on June 10th; when the eggs were laid on June 10th, the second instar larvae were found from June 14th to 16th, and the third instar larvae on June 20th, thus giving from 4 to 6 days for the second instar.

D. Second instar larva.

This is to be found within the corolla tube at the base of the ovary. It may be distinguished from the first instar larva by its greater size, the development of thoracic and abdominal spiracles, and its faintly pink colour. The cuticle is no longer smooth but cuticular papillae and spines are present though inconspicuous. The spatula is not yet present. This instar lasts from 4 to 6 days. The measurements are 1.350×0.350 mm.

E. Third instar larva.

The third instar larva is characterised by the presence of the sternal spatula or anchor process on the ventral surface of the 1st thoracic segment. The spatula is complete but is very light yellow in colour. The larva is still very pale pink and transparent, but the cuticular papillae and spines are well developed. The instar lasts about 4 days. The average measurements are 2.050×0.51 mm.

F. Fourth instar larva.

This is the full-grown larva ready for pupation and measures about 3.0×1.0 mm. It may be recognised by the well-developed, dark brown spatula and the deep pink colour of the body. In 1932, some of the larvae at this stage of development were leaving the flower heads on June 14th (eggs laid May 31st), and when placed on damp sand went down for pupation. Others remained in the heads and were still there on June 22nd, although the heads had been sprayed with water twice daily¹. Heads brought in from the same plants on June 24th contained many larvae, some of which commenced to leave the florets as soon as the heads

¹ Spraying the heads will usually cause the fully grown larvae to come out and drop to the ground. This is a useful method of finding out whether the larvae are full grown or not.

were picked. On the heads being sprayed with water, many of the larvae wriggled out. Others remained in the heads to emerge in gradually decreasing numbers every time the heads were sprayed. The last larvae dropped on July 16th.

In the summer of 1931, ten samples, each of fifty heads of clover, collected on Long Hoos Field, were brought in on June 29th and the heads were sprayed at intervals with water. The last of the larvae dropped on August 14th.

The fourth instar may therefore last as long as 7 weeks before pupation takes place. There is thus a well-marked variation in the duration of the fourth instar.

The larva leaves the head by wriggling up through the corolla tube. It then proceeds to worm itself to the edge of the head, and after hanging there a few moments, drops to the ground. This process may only take about 5 min., and there is no active springing movement. Larvae are usually much more ready to leave a flower head which has been cut, or handled, or sprayed with water.

G. Pupation.

Pupation of the first brood takes place from a few days to a fortnight after the larvae have entered the soil. These larvae spin a cocoon which is of a dull whitish colour and of a parchment-like consistency if formed as normally in the soil, or in coconut fibre, but is roughly studded with sand grains if the larvae have been placed upon sand.

In the case of the 1931 second brood, the larvae had started to drop from the flowers on August 31st, though heads containing larvae were found in the field as late as September 25th. On entering the ground the second brood larva spins a cocoon and over-winters as the fourth instar larva. During the spring of 1932, cocoons were taken from breeding pots in order to ascertain the stage of development. On May 3rd, the larvae brought in appeared to be in the pre-pupal instar; they were comparatively inactive and had assumed the stiffened attitude typical of the pre-pupa. The first pupae were obtained on May 17th and the first adults hatched on May 23rd. This gives a minimum of 6 days for pupation for this brood.

Larvae which were brought indoors and kept on damp sand at laboratory temperature developed rather earlier than those out of doors. Those brought in on April 28th had transformed into pupae by May 3rd, and the first female emerged indoors on May 10th. Others brought in on May 3rd were well-developed pupae by May 10th. By subjecting larvae

192 D. leguminicola (*Lint.*), the Clover Seed Midge

in breeding pots to extra heat in November, Barnes found it possible to obtain adult midges in December.

The pupae are at first very pale pink in colour with opaque wings and eyes. The legs and antennae appear very much swollen. As development proceeds, the eyes gradually darken, the wings become hyaline, the legs and antennae shrink considerably and the abdomen assumes the characteristic colour of the adult. After the cocoon has been left the very delicate cuticle of the empty pupa remains behind on the surface of the soil or coconut fibre.

H. Variation in antennal segment number in the adult.

Wehrle (1924) made a study of the variation in number of antennal segments of this midge. From a study of specimens emerged under conditions of extra heat compared with those emerged under normal conditions, I have found that the proportion of individuals with the larger number of antennal segments is increased. This agrees with Barnes' conclusions (1932) when dealing with the same conditions in the case of *Dasyneura alopecuri* Reuter and *Rhabdophaga heterobia* H.Lw.

V. DAMAGE AND ATTACK.

The damage is caused by the larva which, having penetrated the calyx and corolla, feeds upon the ovary. The first point of attack appears to be at the base of the style, where a ring of brown and withered tissue may be seen. Later the larva eats out crescentic pits in the ovary. Besides the destruction of the ovary, the presence of the larva within the floret also inhibits the development of the corolla and produces a considerable thickening at the base of the corolla tube. An attacked head may be readily recognised by its uneven blooming if partially attacked, or by the suppression of the corollas if completely attacked (see Plate XV, B). It is also much harder to the touch than a normal head (see Plate XV, C).

The number of florets attacked in a head varies considerably. Some heads have been brought in with only two or three florets stunted, in other cases only this number may be normal.

In the autumn of 1929, two samples of about 100 heads each were collected at Kinsbourne Green, Harpenden, and the adults bred out the following spring. The following figures were obtained:

Sample	♂♂	♀♀	Parasites	Total	Average per head
A (100 heads)	507	646	120	1273	12.73
B (100 heads)	790	880	496	2166	21.66

This shows that the average infestation per head may vary considerably even within a small area.

In September 1931 four samples of infested heads (three of 100, one of 75) were again brought in from Kinsbourne Green. The following midges and parasites were bred from them in 1932.

Sample	♂♂	♀♀	Parasites	Total	Average per head
CLS (100 heads)	22	43	13	78	0.78
CLT (")	16	26	13	58	0.55
CLU (")	40	84	10	134	1.34
CLV (75 heads)	68	47	0	115	1.15

It will be seen that the figures are strikingly low in comparison with the figures obtained for heads from the same area two years previously. This may be due partly to the later date at which the sample was collected (September 29th (1931)—September 14th (1929)): many larvae probably had already left the heads.

A rough estimation of the attack of the spring brood on Long Hoos Field was also made in 1931. On June 29th, ten samples of fifty heads of clover, taken at random, and not selected as attacked heads as in the two previous cases from Kinsbourne Green, were brought into the laboratory. Each of these samples was kept until all the larvae appeared to have left the heads. The heads were then examined carefully for any larvae that had not dropped. Table I gives the result:

Table I.

Total number of larvae and average number of larvae per head of red clover on Long Hoos, June, 1931.

Sample (50 heads each)	Total number of larvae	Average larvae per head
1	119	2.38
2	98	1.96
3	93	1.86
4	83	1.66
5	89	1.78
6	84	1.68
7	212	4.24
8	202	4.04
9	192	3.84
10	128	2.56

Other samples of heads were taken from Long Hoos Field on the same date, and the second brood adults and parasites bred out. Table II gives the average infestation.

Thus the infestation on Long Hoos Field in 1931 varied between 1.42 and 4.24 attacked florets per head. This can hardly be considered a serious attack, as it only works out at about 3 per cent. of the crop.

194 *D. leguminicola* (Lint.), the Clover Seed Midge

Table II.

Numbers of D. leguminicola and its parasites reared out of samples taken on Long Hoos, June, 1931.

Sample	Number of heads	♂♂	♀♀	Parasites	Total host and parasite	Average seed lost per head*
CLA	100	40	58	111	209	2.09
CLB	100	25	48	189	262	2.62
CLC	100	39	55	196	290	2.90
CLD	150	48	64	102	214	1.42
CLE	50	10	18	86	114	2.28

* Assuming each parasite is responsible for the death of one midge.

In America, records of heavy injury go back as far as 1879. Lochhead (1904) estimated that the damage done in Ontario in 1903 was one-quarter of the crop or fully half a million dollars. Jarvis (1907) stated that the loss was 25–75 per cent. Creel and Rockwood have described it as the most important pest affecting the production of clover seed.

In Great Britain, it was reported as widely destructive in the seed-growing districts in Montgomeryshire by Jenkins (1926), while Theobald (1929) described fields near Canterbury and Charing in which the crop was ruined. Other reported attacks in 1929 were as follows: in Leicester (Roebuck), in Hertfordshire (M. of A.) and in Buckinghamshire (Jary).

VI. CONTROL.

From the nature of the attack it is obviously impossible to employ insecticides as a means of control; there remain therefore natural control by parasites and cultural methods.

(a) *Parasitism.*

The ability of a parasite to control the outbreak of an insect pest in any particular season is a question on which there is considerable doubt and debate. Usually parasitism, to reduce the numbers of a pest to any extent, should reach 80–90 per cent.; to control a pest it should be over 90 per cent.

Various parasites, chiefly Hymenoptera, have been recorded as attacking the clover seed midge. Comstock (1880) gives *Platygaster error* Fitch and *Eurytoma funebris* Howard; Sanderson (1901) *Tetrastichus corinatus* (Forbes); Folsom (1909) two undetermined species of *Tetrastichus*; Felt (1915) *Telenomus podisi* Ashmead, *Polyrema striaticornis* Girault, *Decatoma* sp., and *Polygnotus* sp.; Wehrle (1929), *Platygaster leguminicola* Fouts and *Inostemma leguminicolae* Fouts.

Wehrle, by examining larvae found in infested clover heads, determined the percentage of parasitism to be 5.71 per cent. for *Platygaster leguminicola* and 2.86 per cent. for *Inostemma leguminicolae* in 1922.

Two species of Hymenoptera, one of which was identified by Waterston as *Tetrastichus roesellae* De Geer, were bred out from the clover-seed midge at Harpenden. For the purpose of estimating percentage parasitism the two species have been considered together.

In the 1930 spring brood from Kinsbourne Green material 616 parasites emerged and the percentage parasitism was about 16. The crest of emergence was about 1 week later than that of the host midge, being on June 6th as compared with May 30th. In the 1932 spring brood figures for parasitism were only available from four breeding pots with heads taken from the same locality. The crest of emergence was 8 days later than in the host midge, and parasitism reached 10 per cent.

In the 1931 spring brood, taken from Agdell¹, parasitism was 27 per cent. and the crest of emergence was on May 23rd, 7 days earlier than the maximum hatch of midges. Parasitism in the second brood from Long Hoos¹ was 47 per cent. and the crest of parasites emerged on July 24th, 10 days before the crest of emergence of the midges which was on August 3rd.

This alteration in relative times of emergence is interesting in view of the fact that Barnes (1930), in dealing with the relative dates of emergence of a midge (*D. alopecuri*) and its parasites on meadow foxtail grass, suggests that the variation in date of emergence of the parasite may be an important factor in increasing the magnitude of fluctuation of parasitism and so the speed at which a parasite might lose or gain its hold over its host. He also suggests that the cause of this variation may be the direct influence of climatic factors, chiefly heat and cold.

(b) Cultural methods.

(i) Variety trials and immunity.

While the clover-seed midge is most commonly found in red clover (*Trifolium pratense*), it has been reported as also occurring in white clover (*T. repens*) by MacDougall (1913), and on Alsike clover (*T. hybridum*) by MacDougall (1913), Folsom (1909) and Wehrle (1929). I have found *Dasyncura* larvae in heads of wild white clover at Harpenden, but have not succeeded in breeding the adult midges. Until this has been accomplished, no satisfactory conclusion regarding the identity of this midge can be reached.

¹ These two fields on Rothamsted Farm are widely separated, and the parasitism figures for each field are probably independent.

196 *D. leguminicola* (*Lint.*), the Clover Seed Midge

The variety trials were set up in order to ascertain whether any particular variety of clover is immune to attack.

Two experiments were carried out in 1931, one at Rothamsted and one at Aberystwyth.

The Rothamsted experiment. For this, the field insectary, a small outdoor house $12\frac{1}{2} \times 9\frac{1}{2}$ ft. and with two beds $12\frac{1}{2} \times 2\frac{1}{2}$ ft. was used. The insectary is shaded by a blind on the west side. The following varieties of clover, ten plants of each variety, were received from the Plant Breeding Station at Aberystwyth for the experiment:

Red clover.

1. Aa 1851. New Zealand Red.
2. Aa 1907. Wild Red.
3. Aa 1829. English Broad Red.
4. Aa 1915. English Late Red.
5. Aa 1849. Swedish Late Red.

White clover.

- I. Ac 737. Wild White.
- II. Ac 836. Dutch White.
- III. Ac 748. New Zealand White.
- IV. Ac 453. Stryno (Danish White).
- V. Ac 453. German Wild White.

Each side of the insectary was divided into five approximately equal areas, and each area into ten blocks. The clover seedlings were then randomised and planted so that each area contained one plant of each variety, red and white. The arrangement is shown in Text-fig. 1.

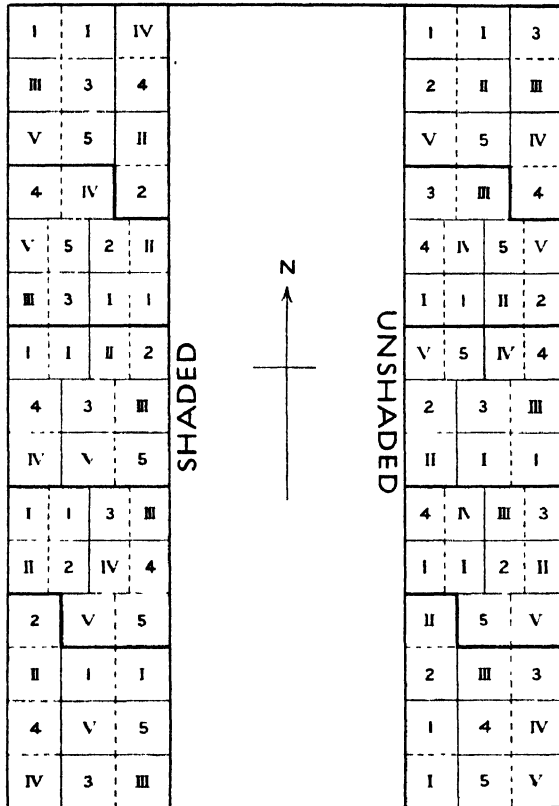
The seedlings were planted on April 23rd and were watered twice a week. All green heads were pinched off until the third week of July, when they were allowed to develop. At the beginning of August, when the second flight of midges was on the wing, there were abundant green heads on all the plants of red clover.

The insectary was infested on six successive days, August 3rd–8th, and in all 70♂♂ and 141♀♀ were liberated in the following numbers:

August 3rd	20 ♂♂	45 ♀♀
4th	4 ♂♂	18 ♀♀
5th	17 ♂♂	30 ♀♀
6th	13 ♂♂	19 ♀♀
7th	10 ♂♂	23 ♀♀
8th	6 ♂♂	6 ♀♀

After this date the insectary was not watered again until all the clover heads had been cut.

On August 25th, full-grown larvae were found in the flower heads, and appeared ready to leave the heads for pupation. On August 31st, all the heads from each plant were cut and placed in paper bags for examination.



Text-fig. 1. Plan of planting varieties of clovers in preference trial (for explanation see text).

About midday it was observed that some of the larvae were leaving the flower heads.

In the laboratory, the heads from each plant were carefully examined, and obviously infested heads placed in glass jars and sprayed with water. The other heads were also sprayed for odd larvae. The larvae which left the heads were counted, and then placed on coconut fibre in breeding pots to serve as material for the following spring. Table III gives the results that were obtained.

Table III.
Results of the variety trial.

Variety of clover	Total heads	Infested heads	% infested	Total larvae	Average larvae per infested head
1. Aa 1851 New Zealand Red	241	101	40.8 \pm 6.06	1045	8.6
2. Aa 1907 Wild Red	540	294	55.6 \pm 3.66	2103	6.59
3. Aa 1829 English Broad Red	301	187	57.3 \pm 4.76	1065	5.8
4. Aa 1915 English Late	351	205	58.5 \pm 4.34	1648	10.7
5. Aa 1849 Swedish Late	602	458	66.4 \pm 5.76	2591	5.3
I-V. Whites	138	0	0	0	0

The first point that arises is that white clover appears to be un-attacked in the presence of abundant heads of red clover. This, however, cannot be considered as proved satisfactorily. The tables show that the flower heads of white clover only averaged 2.76 per plant, whereas the red clovers averaged 40.7 flower heads per plant. This is due to some extent to the different habits of the plants, the reds developing into large and bushy plants completely overgrowing and overshadowing the white clovers. The latter have a creeping habit and their overgrowth by the red clovers appeared to inhibit flowering. For this reason, it was proposed to repeat the experiment in 1932 with the clovers alternating in groups of red and white. Unfortunately, the insectary became infested with millipedes during the winter months, and very few of the plants were unattacked. No observations are therefore available.

The second point of importance that emerges is that none of the five varieties of red clover used proved to be immune under these conditions, neither was there any suggestion that one variety is preferred to another. The percentage of attacked heads ranges from 40.8 in New Zealand to 66.4 in Swedish Late. In both cases the attack is so high as to make any apparent preference of negligible value. Again the average number of larvae per infested head is lowest in Swedish Late (5.3) and highest in English Late (10.7). Of the five varieties attacked, English Late appears to have suffered the most severely, since it combines the second highest number of heads attacked (58.5 per cent.) with the highest average number of larvae per head (10.7). The figures, however, can hardly be considered as satisfactory evidence for the preference of one clover to

another in this group. It is necessary to test other varieties of red clover.

The shading of the west side of the insectary produced no marked effects. The percentage of attacked flowers and the average number of larvae per attacked head was slightly higher on the unshaded half.

The Aberystwyth experiment. This experiment was carried out to see if there was any correlation between the time of flowering and the percentage of attack, and also to confirm the variety trials at Rothamsted. The same red clovers as for the Rothamsted experiment were used, and one white clover, viz. New Zealand White. Samples of the heads of each variety were sent from the Plant Breeding Station at Aberystwyth at fortnightly intervals during the flowering period and were received between July 2nd and October 8th. It was at first proposed that each sample should contain fifty heads of each variety, but on several occasions less were obtained as only that number of heads was in flower. The clover heads were placed in glass jars, sprayed with water at intervals, and the larvae which emerged were counted.

The following samples of heads were received:

Date	New Zealand Red	English Wild	English Broad	English Late	Swedish Late	New Zealand White
July 2nd	50	50	50	13	0	50
„ 15th	50	50	50	50	4	50
„ 29	50	50	50	50	50	50
Aug. 12th	50	50	50	50	50	50
„ 26	50	30	50	50	50	50
Sept. 9th	50	37	50	50	36	50
„ 23rd	50	37	50	50	10	50
Oct. 8th	47	10	22	34	7	50

It will be seen that full counts of heads were received from New Zealand White throughout the season. In New Zealand Red the numbers had fallen off slightly, and in English Broad rather more, in the last sample. English Wild began to fall off early in the season, while English Late which started rather later was late in falling off. Swedish Late was late in starting and early in falling off: only three times were full samples of heads received.

As in the Rothamsted experiment, the white clover was unattacked, while none of the red varieties was immune, all were attacked to a greater or less degree.

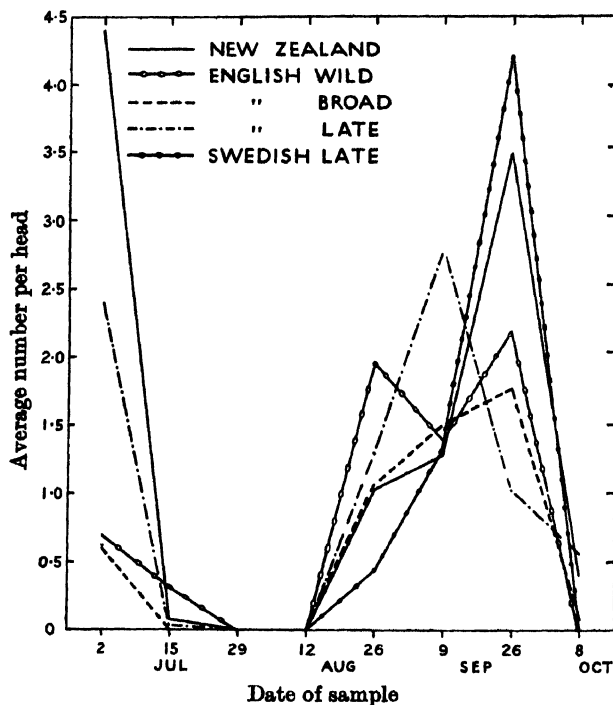
In Text-fig. 2 is shown the average number of larvae per head in each variety at different dates.

New Zealand Red, of which full numbers of heads were obtained on all except the last date, was most heavily attacked by the first brood with

200 *D. leguminicola* (*Lint.*), the Clover Seed Midge

4.4 larvae per head, and had the second heaviest attack by the second brood with 3.5 larvae per head.

English Wild, although full numbers of heads were received until August 12th, was very little attacked by the first brood (0.7). After this date the number of heads fell off and was only 10 on October 8th. The second brood attack appeared on two dates, August 26th (1.95) and September 25th (2.2).



Text-fig. 2. Infestation of varieties of clover at Aberystwyth in 1931.

English Broad shows little attack by either brood (0.6 and 1.85), English Late, although only thirteen heads were received on July 2nd, shows the second heaviest of the first brood infestation (2.4) and the third heaviest of the second brood (2.8).

Swedish Late is completely unattacked by the first brood, but although few heads were received at the end of the flowering period, was the most heavily attacked by the second brood (4.2).

It may be concluded, therefore, that of the five varieties of red clover examined, English Broad was the most satisfactorily free from clover-seed midge attack in 1931, and at the same time produced the second

largest number of heads. New Zealand, which produced the largest number of heads, suffered the worst attack. Since in the insectary trials at Rothamsted, New Zealand was not obviously preferred to English Broad by the clover-seed midge, it appears that the time of flowering must be the deciding factor. Apparently, the greatest number of the flowers of New Zealand, and the least number of the flowers of English Broad were in the green-head stage when the flight of midges was at its maximum. This suggests that if it were possible to select varieties which were at the maximum green-head stage, either some time before, or some time after the crest of emergence of the midges, the damage would be considerably lowered if not entirely absent. Unfortunately, the time of flowering as well as the date of the crest of emergence must vary with latitude, altitude and weather, and the variable nature of the English climate makes any general forecast of very doubtful reliability. It might be possible, however, to advise early or late flowering varieties for different regions and to state that these should not be in the green-head stage, say, during the week from May 28th to June 4th in Harpenden, as the crest of emergence in this locality is usually about May 30th. The unfavourable spring weather of 1932 had the effect of delaying the flowering of the clovers intended for variety trials and life history studies until well after June 3rd, when the flight of midges was at its maximum.

Immunity trials were carried out with German wild white clover, and New Zealand white, but although the females were observed ovipositing, no larvae were found and no adults reared.

(ii) *Pasturing and early cutting.*

The early cutting of the first crop of clover has been recommended by various investigators—Comstock (1880), Creel and Rockwood (1918). The object of early cutting is to catch the larvae in the flower head in the young stage, so that with the drying of the hay, the larva will be killed. Thus by the sacrifice of the first crop a second good crop of seed is ensured, since the second flight of midges will be very much reduced. Creel and Rockwood state that the heads may be left in the field until the larvae are full grown, provided there is no rain. This procedure is dangerous, because if the flowers are cut or handled in any way when the larvae are full grown, or when they are in the fourth instar, a certain number of them will leave the heads and fall to the ground. Larvae in the fourth instar even if not quite full grown are capable of pupation and will develop into normal, if rather smaller, individuals. For example, in the

202 D. leguminicola (*Lint.*), the Clover Seed Midge

1932 brood some of the larvae were ready to leave the heads a fortnight after the eggs had been laid, although the greatest numbers did not drop until they were 3 weeks old, and only then after spraying with water. *The cutting of the first crop should therefore take place as soon as possible, at least not longer than a week after the crest of emergence of the midges.* As has already been indicated this may be fixed somewhere about the end of May or the beginning of June, and farmers should be advised to cut the clover crop as soon after these dates as the attacked heads can be detected in the field. An attacked head can be detected with very little practice within a week of the eggs being laid. Co-operation between the advisory entomologist and the farmer would be of the utmost service, and it should be possible to reduce the pest to very small numbers in the course of a season.

Pasturing, and the destruction of all volunteer clovers, are also suggested as effective methods for ensuring a good second crop of seed (Creel and Rockwood, 1918). The necessity for the use of clean seed need hardly be pointed out. Various methods of killing larvae and pupae within seed have been suggested—heating the seed (Cook, 1881), the use of chloroform or carbon bisulphide (Saunders, 1882), or the use of hot water first at 120° then at 135° just before the seed is sown (Wallace, 1892).

Riley (1879) was of the opinion that if clover growing was abandoned for a few years in the infested areas, this would be an effective means of eradicating the pest.

VII. SUMMARY.

The life history of the clover-seed midge has been studied, and methods of control are discussed. The midge destroying clover seed in England is *Dasyneura leguminicola* Lint., the species common in the United States. It is typically two brooded and the second brood overwinters in the larval state. There are four larval instars.

An attempt was made to establish the immunity of a variety of red clover, but all the varieties used were susceptible to attack. White clover was not attacked. It is suggested that unless an immune variety can be produced, clovers grown for seed production should be chosen with a view to their being in the green-head either before or after the time of maximum emergence of the midges (*e.g.* the week from May 28th to June 4th in Harpenden). Furthermore, if cutting of the first crop is used as a means for destruction of the second brood of midges, this should take place within 10 days of the crest of emergence of the midges, the

farmer deriving what information he requires from the advisory entomologist of his particular district.

VIII. ACKNOWLEDGMENTS.

The writer desires to thank Dr H. F. Barnes for many valuable suggestions and criticism in the methods of experimentation, to Mr A. Gibson of Ottawa and Dr A. E. Brower of Cornell University, Ithaca, N. Y., for samples of infested clover heads, Dr J. Wishart for help with the arrangement of the variety trials, and Captain R. D. Williams of the Welsh Plant Breeding Station, Aberystwyth, for supplying the clover seedlings, and the samples of clover heads, for the variety trials.

The work was carried out during the tenure of a Fellowship of the University of Wales.

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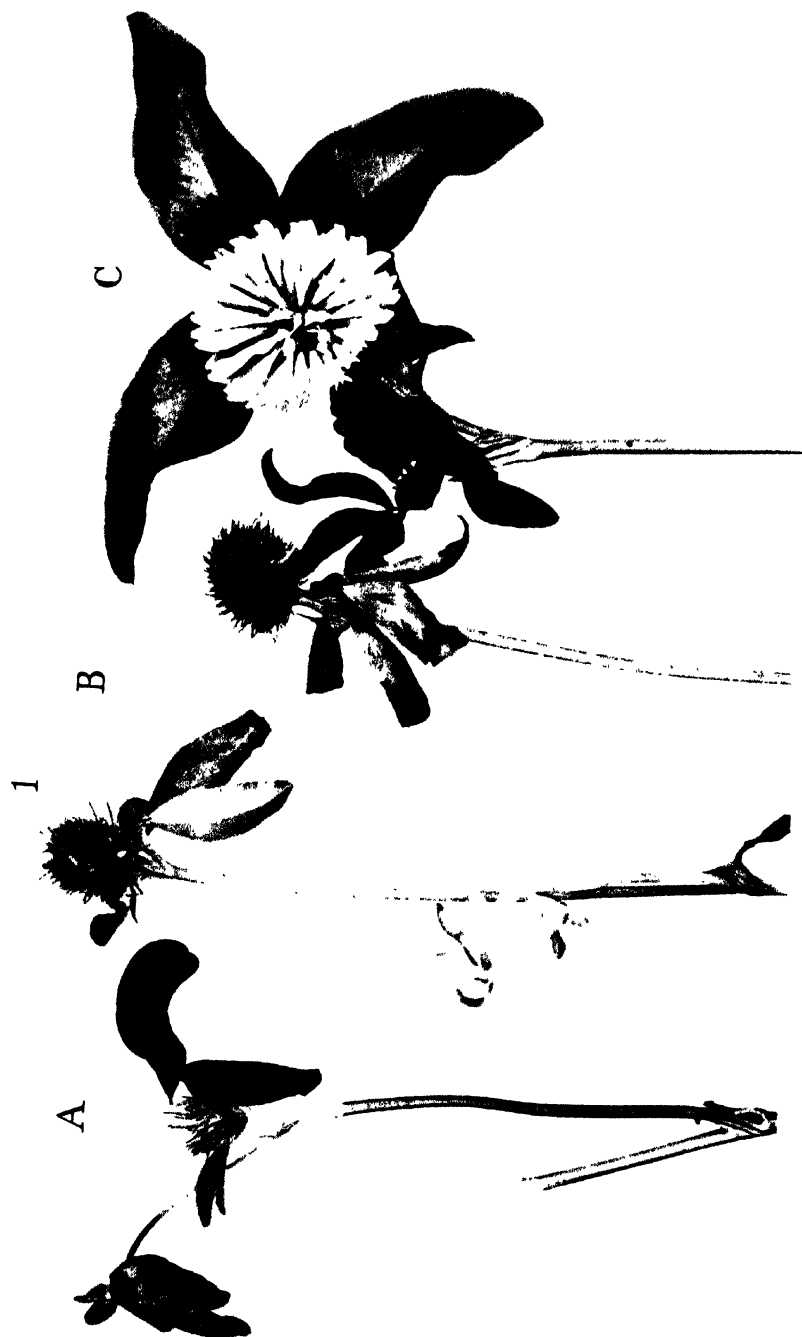
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EXPLANATION OF PLATE XV.

A, green-head in a suitable condition for oviposition; B, attacked heads with larvae (1) leaving for pupation; C, unattacked flower head of red clover.

(Received July 14th, 1932.)



The Morphology and Anatomy of the Larva of *Dasyneura leguminicola* Lint. (Diptera). By MARGOT E. METCALFE, Ph.D., Fellow of the University of Wales (Entomology Department, Rothamsted Experimental Station) *.

(Plates I.–VI.†)

CONTENTS.

	Page
I. Introduction.....	119
II. Morphology	120
III. Anatomy	122
IV. Literature	128

I. Introduction.

The most detailed accounts of the morphology and anatomy of Cecidomyiid larvæ are those of Marchal (1897), whose paper deals with *Cecidomyia destructor*, and Kieffer (1900), who gives general descriptions of typical Cecidomyiid larvæ. The structure and function of the sternal spatula or anchor process have long been subjects of controversy which have attracted the attention of such famous entomologists as Laboulbène (1873, 1893), Osten-Sacken (1893), Giard (1893), Kieffer (1894, 1896), Chaine (1912). Later anatomical studies are those of Williams (1910) on *Cecidomyia resinicoloides* and of Hasemann (1930, 1931) on *Cecidomyia destructor*. A recent paper by Wehrmeister (1925) deals with the comparative anatomy of the digestive tract in Cecidomyiid larvæ, while Felt (1911) and Gabritschewsky (1928, 1930) have devoted attention to the phenomenon of pædogenesis exhibited in *Miastor* spp.

The present paper is an attempt to investigate in some detail the morphology and anatomy of the third and fourth instars of the larva of *Dasyneura leguminicola* Lint., a common pest of red clover in Great Britain. It is also a preliminary to the study of the structure and development of the reproductive system in the Cecidomyidæ.

Until recently the number of ecdyses undergone by larval Cecidomyids has been unknown. Hamilton (1925) is the only author who states a definite number (four) of instars; Marchal, Kieffer, and others divide the life of the larva into "phases," each of which may comprise one or more ecdyses. According to Marchal there are three larval phases in the life-cycle of *Cecidomyia destructor*, viz. :—

1. "La phase de migration," the newly emerged larvæ before feeding has commenced.
2. "La phase de nutrition et de croissance," the actively feeding larva.
3. "La troisième forme larvaire," the quiescent, non-feeding larva within the pupal case.

* Communicated by H. F. BARNES, M.A., Ph.D., C.M.Z.S.

† For explanation of the Plates, see p 130.

These phases appear to be distinguished by physiological rather than morphological differences. Morphologically the third-form larva appears to be characterized by the presence of a complete sternal spatula, its peculiar cuticular papillæ, and the pupal case. The second-form larva has none of these distinguishing features, although the spatula may be present in its incomplete form; it differs from the first larva by its relatively thicker cuticle, the development of the imaginal buds, and by the fact that the digestive tract now contains a certain amount of food material.

In *D. leguminicola* Lint. there are four larval instars. These are readily distinguishable from each other by morphological differences. The first instar larva is characterized by its smooth cuticle, without spines or papillæ. No sternal spatula is present and only one pair of spiracles is open, viz., the eighth abdominal spiracles. It is almost transparent, and measures about 0.35×0.08 mm. In the second instar the larva shows some development of cuticular spines and papillæ, but these are not prominent. All the spiracles are present and open; there is no sternal spatula. The larva measures about 1.35×0.35 mm.

The third instar larva is faintly pink in colour, with well-developed papillæ and spines; it is provided with a complete spatula, which is very pale yellow in colour. Its average measurements are 2.05×0.51 mm.

The fourth instar larva is deep pink in colour and the spatula is dark brown. The larva is very active, and will leave the flower-heads when they are cut or during a shower of rain. It measures about 3×1 mm., and in this stage constructs a cocoon for pupation in spring or for overwintering in autumn.

The construction of a cocoon does not appear to be indispensable to successful overwintering, as in March 1932, after six weeks drought and exceedingly cold weather, larvæ without cocoons were found on the surfaces of the fibre in breeding-pots apparently in as good condition and equally as responsive to stimuli as were larvæ of the same generation which had overwintered in a cocoon.

Feeding takes place in all four instars, and the spatula has never been observed in the half-grown stage described by Kieffer, Chaine, and Hamilton.

II. Morphology.

The body of the larva is composed of thirteen well-defined segments forming the three characteristic regions—head and supernumerary segment, thorax (three segments), and abdomen (nine segments). The terminal abdominal segment is much reduced and bears the anus.

A. THE HEAD. (Pl. I figs. 1 & 2)

The head is small but well developed for a dipterous larva. Dorso-laterally it bears a pair of apparently two-segmented tentacles. The mouth is ventral and is bordered by a dorsal appendage, a ventral appendage, and a pair of lateral appendages. If Kellogg is correct, and the mouth-parts of the adult develop in close relation to the mouth-parts of the larva, then these appendages may represent the labrum-epipharynx, the labium, and the maxillary palps. According to Hamilton there are two pairs of lateral appendages, representing mandibles and maxillæ, in *Monarthropalpus buxi*. This does not agree with Kellogg's hypothesis stated above, since the mandibular sclerites are absent in the Cecidomyiidae. The posterior border of the head is supported by a ring of chitin, which has two lateral prongs directed posteriorly. The super-

numery segment or neck appears to belong to the head rather than to the thorax for two chief reasons, viz., that it bears the eye-spots ("taches oculaires"), which are thought to be the visual organs of the larva, and that the first pair of spiracles is not situated here but on the segment following.

The eye-spots are a pair of darkly pigmented crescentic bodies placed back to back in the supernumerary segment; they are situated deeply within the tissues and in close connection with the cephalic sacs, which give rise to the imaginal buds of the eyes. According to Marchal they have a central body comparable to a crystalline lens and represent the ocelli. Kieffer states that he was unable to find this lens, which was also absent in all the larvæ examined by me.

The head and supernumerary segment are readily withdrawn into the thorax.

B. THE THORAX.

The first thoracic segment bears a pair of spiracles dorsally. No spiracles are present on the second and third segments. Marchal, however, records a pair of spiracles on the metathorax in *Mayetiola destructor* Say.

On the ventral surface of the prothorax is borne the characteristic organ so typical a feature of Cecidomyid larvæ—the sternal spatula or anchor process. This is a strongly chitinised rod, deeply bilobed and free anteriorly, and with its posterior extremity rounded and sunk into a pocket formed by the body-wall. As has already been indicated, Marchal, Kieffer, and other investigators state that the spatula is only present in the full-grown larva. In *Dasyneura leguminicola* it is complete in the third and fourth instars (Pl. I fig. 3).

With regard to the function of the spatula opinions are still at variance. Giard, in 1893, stated that the spatula may take on the rôle of the mouth-parts where these are incomplete, or may be used as a locomotory organ in the case of gregarious larvæ which pupate in the soil and need some means of dispersal to prevent overcrowding. The movement effected is a spring or leap caused by the sudden release of the spatula from the terminal corneous papillæ with which it has been engaged. Kieffer's observations in 1894 were directly contradictory to this hypothesis. He stated that larvæ pupating within galls were provided with a strongly chitinised and well-developed spatula, while in those seeking the earth at maturity it was a simple, almost hyaline rod. In the former case it was used for the purpose of rubbing a thin patch in the wall of the gall, so that the emergence of the adult might be facilitated. Laboulbène (1893) reported that the function of the spatula was the separation of the upper from the lower epidermis of the leaf in leaf-mining larvæ, their mouth-parts being too weak for this purpose. Marchal's view was that the spatula was used by *Cecidomyia destructor* in reversing the position of the larva in the flax-seed case. I have made no observations either with regard to the spatula as an accessory mouth-part or as an organ of locomotion. *Dasyneura leguminicola* pupates in the soil, and the majority of the larvæ leave the flower-heads by falling to the ground after a shower of rain. The larva wriggles its way up through the corolla and from floret to floret until the edge of the heads is reached; here it hangs for a few moments, and finally drops to the ground. There is no active springing or leaping movement. In many of the larval cases which were opened the larvæ were found, not lying stretched out in the case, but doubled up at one end of it. This may easily be a stage in the process of reversal described by Marchal.

There seems to be, however, no reason to suppose that the spatula has the same function in different species: it certainly appears to be used for leaping in *Contarinia* spp.

The spatula appears to be purely a product of the ectodermal layer, but the chitin composing it is of a different constitution to that of the general cuticular layer, since it stains a different colour than the latter. It cannot therefore be considered as merely a thickened portion of the latter. The spatula is in the shape of a rod or shaft with its extremities expanded and flattened. The posterior extremity is curved somewhat in the shape of the crown of an anchor. The anterior extremity is deeply incised or bilobed. In transverse section the shaft is seen to be rectangular (Pl. I. fig. 6). The posterior end of the spatula is completely sunk into a fold of ectoderm (Pl. I. fig. 4). The ectodermal cells in this region are very small. Anteriorly the fold opens out to form a groove in which the shaft of the spatula lies; here the ectodermal cells are much larger and form a conspicuous layer (Pl. I. fig. 5). At its anterior extremity the shaft is flush with the body-wall, but is still covered by a thin layer of cuticle. The forked end of the spatula is quite free.

C. THE ABDOMEN.

There are nine abdominal segments, the first eight of which each bears a pair of spiracles. The spiracles are situated laterally and in the first seven pairs about one-third of the length of the segment from its anterior border. The last pair of spiracles is placed nearer the mid-dorsal line and the posterior border of the segment. The ninth segment bears ventrally the anus. It is also provided with two pairs of terminal setæ (Pl. I. fig. 7).

The arrangement of the cuticular papillæ and spines has not been worked out, but it was noted that, immediately posterior to each spiracle and also in about the same position on the non-spiracular segments, is a well-developed, posteriorly directed seta.

III. Anatomy.

A. THE DIGESTIVE SYSTEM. (Pl. I. fig. 8; Pl. II. fig. 9.)

The digestive system comprises three primary regions, the fore-, mid-, and hind-intestines, consisting of œsophagus, proventriculus, ventriculus, ileum, colon, and rectum, with the salivary glands and Malpighian tubes.

1. *The Fore-Intestine.*

The fore-intestine is derived from the stomodæum and consists of the buccal cavity and the œsophagus.

The mouth is a small aperture on the ventral surface of the head, bordered by the rudimentary mouth-parts already described, and opening by a narrow passage into the buccal cavity (Pl. II. fig. 10). At its posterior border the buccal cavity is supported by the pharyngeal skeleton, which consists of a half-hoop of chitin, incomplete ventrally. The ventral horns of this skeleton are hook-like and directed anteriorly (Pl. II. figs. 11 & 12). The buccal cavity receives the openings of the œsophagus and common salivary duct (Pl. II. fig. 10; Pl. III. fig. 13). The œsophagus is a very slender tube of uniform diameter extending from the buccal cavity into the third thoracic segment. Between the second and third thoracic segments it passes through the nerve-collar formed by the supra- and subœsophageal ganglia with their connectives. The wall of the œsophagus is formed by a layer of small and regular cells. It has a conspicuous chitinous lining (Pl. III. fig. 15). No muscles are present, and, indeed, the absence of musculature is a striking feature of the digestive system.

Hasemann states that the fore-intestine is composed of two regions, the pharynx and œsophagus, the former corresponding with the buccal cavity described above. Since the salivary ducts open into this region, the latter seems the more convenient term for use. Williams describes in *Cecidomyia resinicoloides* a dorsal blind sac with a "curious dark purplish-brown object" in its middle, which lies in the head. The purplish-brown object appears to be the eye-spot, while the dorsal blind sac, which he suggests is a food reservoir, is the buccal cavity.

2. The Mid-Intestine. (Pl. II. fig. 9; Pl. III. figs. 16 & 17.)

In the third thoracic segment the œsophagus opens into the proventriculus. The passage from fore- to mid-intestine is simple and without an œsophageal valve. The proventriculus is a short tube extending into the first abdominal segment. It is considerably wider in diameter than the œsophagus, and its wall differs noticeably in structure, being composed of about four large cells (Pl. III. fig. 16). Wehrmeister considers this structural difference sufficient reason for including the proventriculus in the mid-intestine instead of in the fore-intestine, as do Marchal and Kieffer.

Towards the posterior border of the first abdominal segment the proventriculus passes insensibly into the ventriculus or stomach. This is a large sac-like structure ending blindly between the fifth and sixth abdominal segments. At its widest part it occupies about one-third of the volume of the hæmocœle. The cells composing its wall are similar to those lining the proventriculus, but are larger and flatter. Its cavity is very wide and contains a considerable amount of food-material (Pl. III. fig. 17).

3. The Hind-Intestine. (Pl. III. figs. 18-21.)

There is no connection between the mid- and hind-intestines, and the latter appears to contain none of the products of excretion. It is a straight tube, varying in structure and diameter, extending from the anterior border of the fifth abdominal segment, where it lies dorsal to the ventriculus, to open in the anus on the ninth segment. At its anterior end the hind intestine gives rise to a pair of Malpighian tubes (Pl. III. figs. 18 & 26).

Immediately posterior to the origin of the Malpighian tubes the hind-intestine is a slender tube lined with a layer of large regular cells which almost obscure the cavity. This is the ileum, and it extends to the posterior border of the seventh segment (Pl. III. fig. 19). Here it is succeeded by the colon, which is of much greater diameter and is lined by flat irregular cells. Its walls are collapsed and lie one against another, presumably owing to the lack of contents (Pl. III. fig. 20).

The colon extends to the ninth segment, where it passes into the very short rectum (Pl. III. fig. 21). This is of a much smaller diameter; the cells composing its wall are large and columnar, and appear to be glandular. This region may represent the region of the rectal glands. The hind-intestine is quite straight, and does not fall into loops, as described by other authors—Marchal, Kieffer, Williams, and Wehrmeister. With the exception of Marchal these writers also state that the fore- and hind-intestines are in communication with each other.

4. The Salivary Glands. (Pl. III. figs. 22-25.)

The salivary glands are a pair of large and conspicuous organs extending one on either side of the ventriculus into the fourth abdominal segment. Anteriorly they open into the buccal cavity by a common duct, the aperture

of which is situated at the apex of a papilla, which may represent the epipharynx. Marchal and Kieffer both term this papilla the ligula.

The gland itself is composed of three distinct regions, the first and posterior extending from the fourth abdominal to the second thoracic segment, the second a short portion in the second thoracic segment, and the third passing anteriorly into the short lateral duct, which joins with its fellow of the opposite side immediately anterior to the eye-spots.

The main bulk of the gland, i.e., that portion lying in the abdomen and posterior region of the thorax, is lined by two rows of very large cells, between which runs a wide duct filled with a secretion. The gland here is much convoluted, its cells have very large nuclei, and it is evidently the actively secreting region (Pl. III. fig. 22). Anteriorly, in the second region, the duct is much smaller in diameter and is surrounded by four rows of irregular cells (Pl. III. fig. 23). This structure is in its turn replaced by the two-celled condition, though now very much reduced in size (Pl. III. fig. 24), which passes into the lateral duct (Pl. III. fig. 25). The salivary duct has a very conspicuous chitinous lining.

5. The Malpighian Tubes. (Pl. III. fig. 26.)

A single pair of Malpighian tubes is present, arising from the hind-intestine at its anterior extremity (Pl. III. fig. 18). In the living larva they are very conspicuous through the cuticle owing to their yellowish colour. They form a loop anteriorly into the fourth abdominal segment, turning dorsally upon themselves to run parallel to the ileum, and thus assuming the characteristic T-shaped formation. They end in the seventh segment (Pl. I. fig. 8). Internally the Malpighian tubes are lined by two rows of large cells with conspicuous nuclei. The duct between these cells varies in diameter, but is usually wide (Pl. III. fig. 26).

B. THE RESPIRATORY SYSTEM. (Pl. IV. figs. 27 & 28; Pl. V. figs. 29-31.)

1. The Spiracles.

Nine pairs of spiracles are present, a pair on the prothorax and a pair on each of the first eight abdominal segments. This seems to be the usual number of spiracles present in Cecidomyid larvæ, though Marchal and Hasemann both record ten pairs for *Mayetiola destructor*. Kieffer also gives ten pairs for *Rhizomyia perplexa* Kieff., the extra pair being on the anal segment.

A spiracle is a flask-shaped structure, the neck of the flask forming a conspicuous chitinous tube above the general level of the cuticle, while the bulb of the flask forms the atrium. The spiracular opening is situated at the apex of the chitinous tube, is simple, devoid of lips and closing apparatus. The atrium is provided with a delicate network of protoplasmic strands or trabeculae traversing its cavity (Pl. V. fig. 29).

2. The Tracheæ.

The tracheal system consists of a series of longitudinal trunks connected by transverse branches. According to Marchal, Kieffer, and Hasemann two pairs of longitudinal trunks, a dorsal and a ventral pair, are present. Williams, however, describes an additional pair of lateral longitudinal trunks in *Cecidomyia resinicoloides*.

In *Dasyneura leguminicola* two pairs of longitudinal trunks, a dorsal and a ventral pair, are present. The dorsal trunks are connected with the

ventral trunks in each segment by lateral tracheæ, ten pairs of which are present altogether. No lateral trachea is present in the prothoracic segment. In the middle of its length each lateral trachea of the eight abdominal segments gives off a short spiracular branch which passes outwards to open into the atrium of the spiracle. The spiracular branch to the prothoracic spiracle arises from the main dorsal longitudinal trunk (Pl. IV. figs. 27 & 28; Pl. V. figs. 30 & 31).

The dorsal tracheal trunks are connected with each other in the abdominal segments by complete transverse branches (Pl. IV. fig. 27). These arise about midway between the origins of the lateral tracheæ, and each gives off a pair of fine tracheæ which pass anteriorly, their ramifications supplying the segment. In the thorax the transverse branches are incomplete and do not form a closed system across the segment. The dorsal tracheal trunks are prolonged anteriorly into the head, giving off a spiracular branch to the prothoracic spiracle. Other branches supply the spatula, eye-spot, and pharyngeal skeleton.

I was unable to find the dorsal ampullæ described by Marchal, Kieffer, Williams, and Hasemann. According to Kieffer there is no complete connection between the dorsal longitudinal tracheal trunks, but a short trachea, terminating in an ampulla, arising from each. Marchal and Williams state that these ampullæ are closely opposed to each other, while Hasemann states that the transverse tracheæ meet in the median line in a distinct round enlargement. There is no trace of either ampullæ or enlargement in *Dasyneura leguminicola*.

The ventral tracheal trunks, instead of being connected in the abdominal segments as are the dorsal trunks, have transverse connections only in the second and third thoracic segments (Pl. IV. fig. 28). In the first to seventh abdominal segments each trunk gives off two branches. The anterior of these runs first of all transversely, and then, after a right-angle bend, parallel to the long axis of the body. It supplies the posterior region of the segment immediately anterior as well as the anterior region of the segment of its origin. The second branch is transverse and is very finely divided; its ramifications supply the median and posterior regions of its segment of origin. Both branches arise posteriorly to the lateral trachea.

The longitudinal trunks are not straight, but appear to be pulled out of line laterally by the lateral tracheæ and medianly by the transverse tracheæ; they thus have a zig-zag course.

C. THE NERVOUS SYSTEM. (Pl. V. fig. 32.)

The nervous system consists of the brain or supra-œsophageal ganglion and the ventral nerve-cord.

The brain is situated dorsal to the œsophagus between the second and third thoracic segments. It is large and obviously composed of a pair of fused ganglia (Pl. V. fig. 32).

The ventral nerve-cord consists of eight ganglia. The first of these is the subœsophageal ganglion, which is situated in the thorax ventral to the œsophagus and slightly posterior to the supra-œsophageal ganglion or brain. The œsophageal ganglia are connected by a pair of short and stout connectives, the parœsophageal connectives, the whole complex forming a nervous collar traversed by the œsophagus (Pl. V. fig. 32).

The remaining ganglia of the ventral nerve-cord are concentrated in the first three abdominal segments and are connected by short fused connectives.

Segmental nerves arise from the ganglia, those given off by the terminal ganglion forming a plexus which supplies the posterior region of the abdomen.

The ganglia exhibit the typical structure—a central medullary substance surrounded by groups of nerve-cells, the whole invested by a syncytial membrane.

D. THE CIRCULATORY SYSTEM. (Pl. V. fig. 33.)

The dorsal vessel extends from the posterior border of the second thoracic segment to the seventh abdominal segment; for the most part it lies close to the dorsal body-wall and is composed of seven ventricles, the first being situated in the third thoracic segment. The ventricles are large and may be oval or quadrangular; each is provided laterally with a pair of osira. Between the ventricles the vessel is much compressed dorso-ventrally. Anterior to the first ventricle it is prolonged as a laterally compressed tube, the aorta, which leaves the mid-dorsal line and terminates immediately dorsal to the supra-oesophageal ganglion.

The alary muscles are well developed and support two rows of pericardial cells. The latter are large cells arranged in segmental groups of about four. In the anterior region—that is, in the thorax and first abdominal segments—the grouping is well defined, but towards the posterior region of the dorsal vessel the cells tend to form two continuous lines. The wall of the dorsal vessel is delicate.

No observations of the vessel in the living larva were made, so it is impossible to record the rate of pulsation.

E. THE MUSCULAR SYSTEM. (Pl. VI. fig. 36.)

The muscular system may be divided into two sections, splanchnic and somatic muscles. Owing to the reduction or absence of the splanchnic muscles already noted the following account deals only with somatic muscles:—

The somatic muscles are paired and are arranged in segmentally repeated groups, there being some modifications in the anal and cephalic segments. In general the muscles arise in the intersegmental membrane, and are inserted into the corresponding region of the segment posteriorly. In some cases the muscles are short and arise some distance along the segment.

1. *General Segmental Muscles.*

These form the musculature of the thorax and abdomen, and are divided into two main groups—longitudinal and dorso-ventral.

a. *Longitudinal Muscles.*

(i.) *Dorsal Longitudinal Muscles.*

Eleven pairs of dorsal longitudinal muscles are present, nine of these extending the whole length of the segment, the remaining two pairs being short. Of these muscles five pairs are purely longitudinal, six pairs are oblique.

Three pairs of the purely longitudinal muscles arise from the tergum and are inserted therein, one pair being short. The other two pairs of longitudinal muscles arise from and are inserted into the dorsal region of the pleuron, one pair being short. Of the oblique muscles two pairs arise from the lateral region of the tergum and are inserted into its dorsal region, two pairs arising from its dorsal region are inserted laterally, one pair arises from the pleuron and is inserted into the tergum, and the remaining pair arises from the tergum and is inserted into the pleuron.

(ii.) *Ventral Longitudinal Muscles.*

There are also eleven pairs of ventral longitudinal muscles, of which three pairs are short.

The five pairs of purely longitudinal muscles, three of which arise from and are inserted into the sternum and two into the pleuron, are all long muscles. The remaining six pairs of muscles are oblique. Of the three short pairs all arise from the sternum, the first near to the middle line at about the level of the spiracle, the second external to the first, the third external to the second and a little posterior to it. The first of these three pairs is inserted into the lateral region of the sternum, the other two pairs into the pleuron.

One of the pairs of long oblique muscles arises from the sternum and is inserted into the pleuron, the other two pairs arise from the pleuron and are inserted into the sternum.

b. *Dorso-ventral Muscles.*

Eight pairs of dorso-ventral muscles are present in each segment, six pairs of which are vertical, two pairs oblique.

The vertical muscles are divided into two groups, three pairs being pre- and three pairs post-spiracular. One pair of the pre-spiracular muscles is tergo-sternal, the others are all pleural. The post-spiracular muscles are also pleural.

Of the oblique muscles the one pair arises dorsally from the intersegmental membrane and is inserted into the ventral border of the pleuron posterior to the spiracle. The other pair arises dorsally from the pleuron posterior to the spiracle, and, passing backwards, is inserted ventrally into the intersegmental membrane.

2. *Anal Muscles.*

In the anal segment the general segmental muscles are absent and a special musculature controlling the anus is present. This consists of four pairs of muscles, two of which are lateral, one dorsal, and one ventral.

The lateral muscles arise from the tergo-pleural and sterno-pleural angles of the anal segment, and, converging, are inserted into the fold of ectoderm surrounding the anus. They thus form a St. Andrew's cross.

The dorsal muscles arise from the dorsal region, the ventral muscles from the ventral region of the eighth to ninth intersegmental membrane. They are inserted into the dorsal and ventral regions of the anal ectodermal fold.

3. *Cephalic Muscles.*

The muscles controlling the tentacles and mouth-parts are so small as to render it impossible to follow them out satisfactorily.

The retraction of the head into the thorax is effected by a series of longitudinal muscles arising from the chitinous ring at the posterior border of the head and inserted into the anterior border of the prothorax. These fall into two groups, there being eleven pairs of dorso-lateral muscles and six pairs of ventro-lateral muscles.

F. THE FAT-BODY. (Pl VI. fig 34.)

The fat-body consists of segmentally arranged lobes, two lateral and one median ventral. These do not take up more than one-third of the space in the body-cavity of a full-grown larva. The ventral lobe is absent in the anal

and first two thoracic segments. The lateral lobes in the anal and first thoracic segments are very small.

The ventral lobes are rounded, while the lateral ones are irregular in shape.

G. IMAGINAL DISCS. (Pl. II. fig. 9; Pl. VI. fig. 35.)

The imaginal discs of the legs and wings are present in very young larvæ as thickened plates of ectoderm. As the larva matures these rudiments undergo the typical development, first sinking into ectodermal pockets and then being thrust outside the body.

The imaginal discs of the head, or "cephalic histoblasts" (Marchal, Kieffer), follow a more complicated course, and fall into two groups: (1) the imaginal discs of the eyes and antennæ; (2) the imaginal discs of the mouth-parts. Hitherto the larvæ examined have shown no trace of the imaginal discs of the mouth-parts.

The eyes and antennæ are formed in two ectodermal sacs which arise from the anterior and dorsal region of the head. These sacs sink side by side into the body-cavity, their blind ends terminating in the head a little posterior to the eye-spots. The ectodermal cells lining these cavities bud off two thickened plates, the posterior pair being the rudimentary antennæ and the anterior pair, which are in close connection with the eye-spots, the rudimentary eyes (Pl. II. fig. 12; Pl. III. figs. 13 & 14; Pl. VI. fig. 35). At pupation these sacs are everted and antennæ and eyes lie outside the body in the normal manner.

H. THE REPRODUCTIVE ORGANS.

No external genital appendages are present in the larva. The ovaries or testes consist of a pair of oval bodies situated dorsally in the sixth abdominal segment. Posteriorly they are drawn out into short delicate threads, the rudiments of the mesodermal portion of the efferent system. A description of the structure and development of the reproductive system is to be dealt with in a subsequent paper.

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Lettering.

a. = anus.
 A1-9. = abdominal segments.
 al. = alary muscle.
 at. = atrium.
 bc. = buccal cavity.
 c. = " crown " of sternal spatula.
 co. = colon.
 conn. = œsophageal connective.
 c.r. = chitinous ring.
 ct. = cuticle.
 dlm. = dorsal longitudinal muscle.
 dt. = dorsal tracheal trunk.
 dtb. = dorsal transverse branch.
 dto. = dorsal segmental trachea.
 dv. = dorsal vessel.
 dvm. = dorso-ventral muscle.
 e. = eye-spot.
 ect. = ectoderm.
 ect.p. = ectodermal plate in region of spatula.
 f. = forks of sternal spatula.
 ft. = fat-body.
 h. = head.
 i. = ileum.
 im.a. = imaginal bud of antenna.
 im.e. = imaginal bud of eye.
 im.l. = imaginal bud of leg.
 im.w. = imaginal bud of wing.
 l. = labrum.
 lf. = lateral fat-lobe.
 li. = labium.
 lt. = lateral tracheal trunk.
 m. = mouth.
 me. = medulla.

m.t. = Malpighian tube.
 mu. = muscle.
 mx. = maxillary palp.
 n.c. = groups of nerve-cells.
 œs. = œsophagus.
 œs.g. = œsophageal ganglion.
 p. = papilla with opening of salivary duct.
 pc. = pericardial cell.
 ph.s. = pharyngeal skeleton.
 pr. = proventriculus.
 r. = rectum.
 s. = shaft of sternal spatula.
 S. = sternite.
 s.d. = salivary duct.
 sg. = salivary gland.
 sp. = spiracle.
 spb. = spiracular branch of trachea.
 st. = sternal spatula.
 sub.g. = subœsophageal ganglion.
 sup.g. = supra-œsophageal ganglion.
 syn. = syncytial membrane.
 t. = tentacle.
 T 1-3. = thoracic segments.
 tb. = trabecula.
 tr. = trachea.
 ts. = terminal seta.
 v. = ventriculus.
 vf. = ventral fat-lobe.
 vlm. = ventral longitudinal muscle.
 vt. = ventral tracheal trunk.
 vtb. = ventral transverse branch.
 vto. = ventral transverse trachea.

EXPLANATION OF THE PLATES.

PLATE I.

- Fig. 1. The head and supernumerary segment. Dorsal view. $\times 22$.
 2. The head. Ventral view. $\times 45$.
 3. The sternal spatula. Surface view. $\times 30$.
 4. Transverse section through first thoracic segment, showing crown of spatula completely covered by cuticle. $\times 240$.
 5. Section anterior to fig. 4, showing spatula in groove. $\times 240$.
 6. Section through shaft of spatula, flush with body-wall. $\times 240$.
 7. Terminal abdominal segments. Ventral view. $\times 6$.
 8. The digestive system and its appendages. Dorsal view. $\times 7$.

PLATE II.

- Fig. 9. Longitudinal section through the anterior region of the body. $\times 90$.
 Figs. 10-12. Longitudinal sections ventral-dorsal through the anterior region of the body. $\times 300$.

PLATE III.

- Figs. 13 & 14. Longitudinal sections ventral-dorsal through the anterior region of the body. $\times 300$
 Fig. 15. Transverse section through the oesophagus. $\times 525$.
 16. Transverse section through the proventriculus. $\times 450$.
 17. Transverse section through the ventriculus $\times 150$
 18. Transverse section through the origin of Malpighian tubes. $\times 300$.
 19. Transverse section through ileum. $\times 525$.
 20. Transverse section through colon $\times 450$.
 21. Transverse section through rectum $\times 375$
 22. Transverse section through posterior region of salivary gland. $\times 210$.
 23. Transverse section through median region of salivary gland. $\times 547$.
 24. Transverse section through anterior region of salivary gland. $\times 570$.
 25. Transverse section through salivary duct. $\times 1125$
 26. Transverse section through Malpighian tubes. $\times 352$.

PLATE IV.

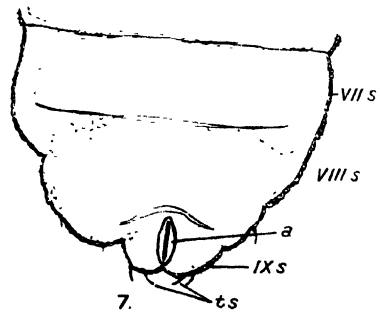
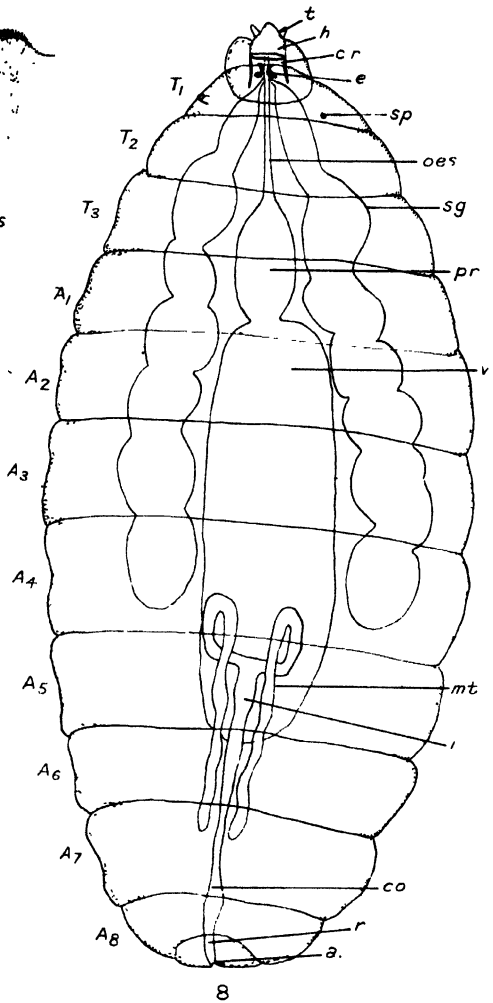
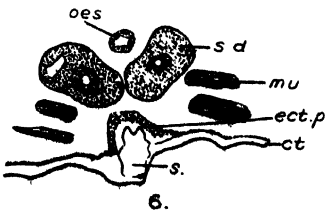
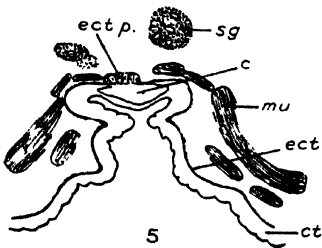
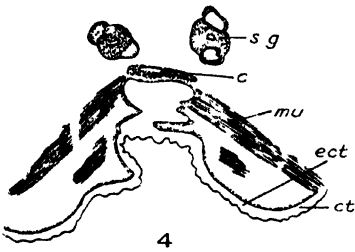
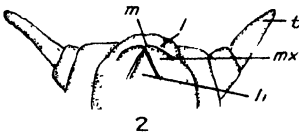
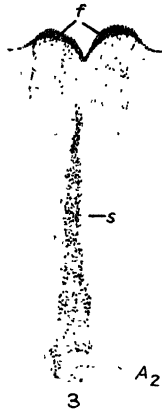
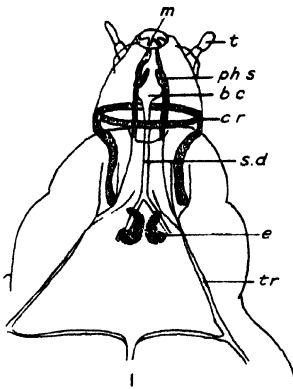
- Fig. 27. The tracheal system. Dorsal view. $\times 8$.
 28. The tracheal system. Ventral view. $\times 8$.

PLATE V.

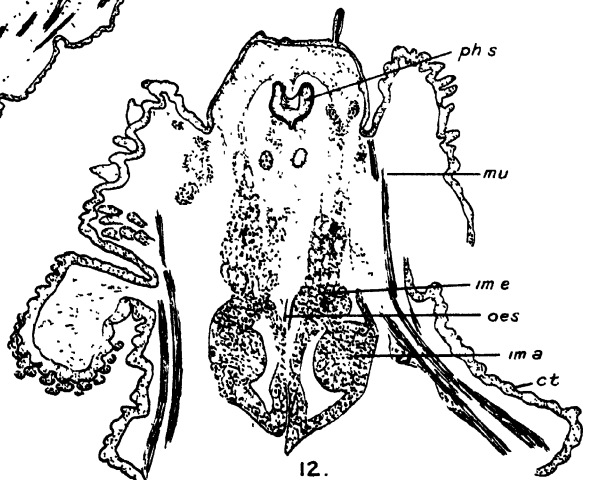
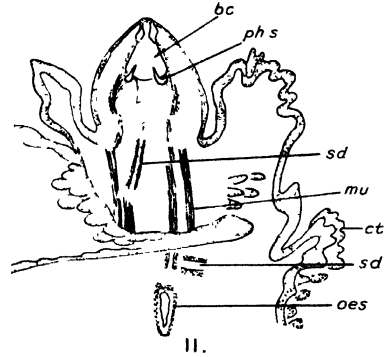
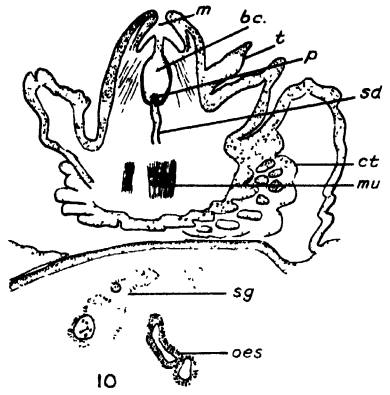
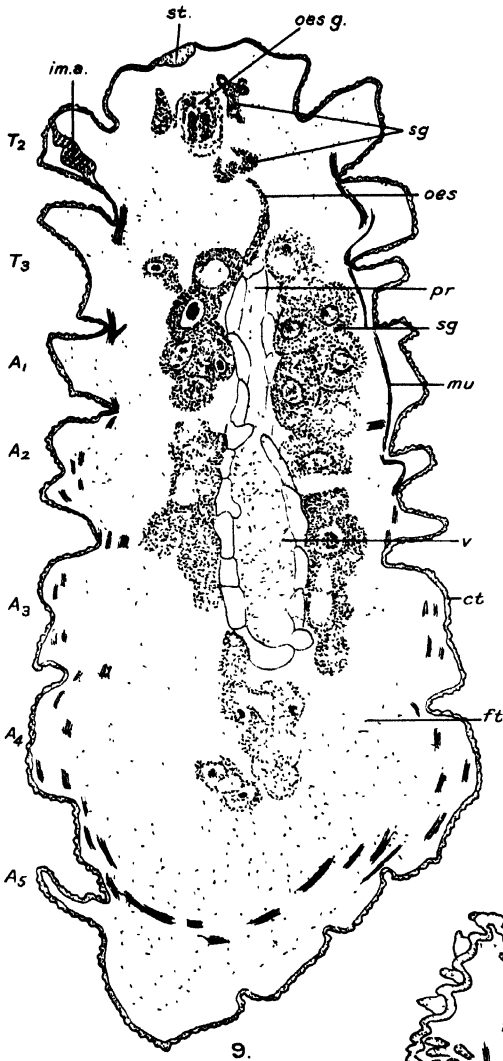
- Fig. 29. Transverse section through a spiracle $\times 1162$.
 30. The tracheal system. Antero-lateral view. $\times 8$.
 31. The tracheal system. Postero-lateral view. $\times 8$.
 32. Transverse section through the oesophageal collar. $\times 225$.
 33. Transverse section through the dorsal vessel. $\times 315$.

PLATE VI.

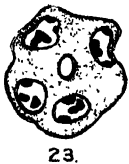
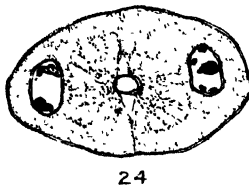
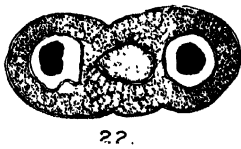
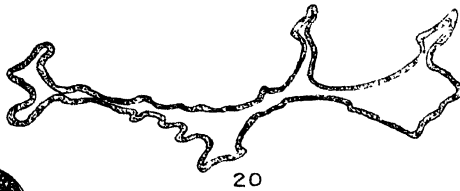
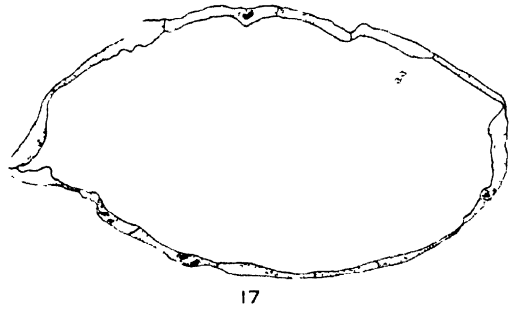
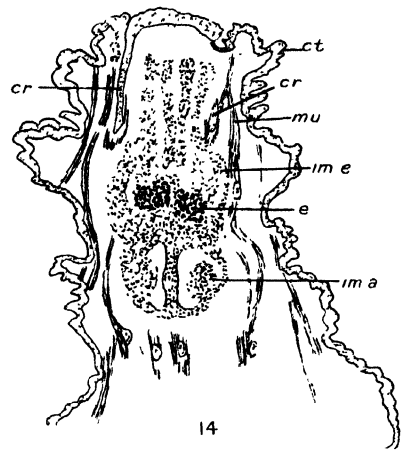
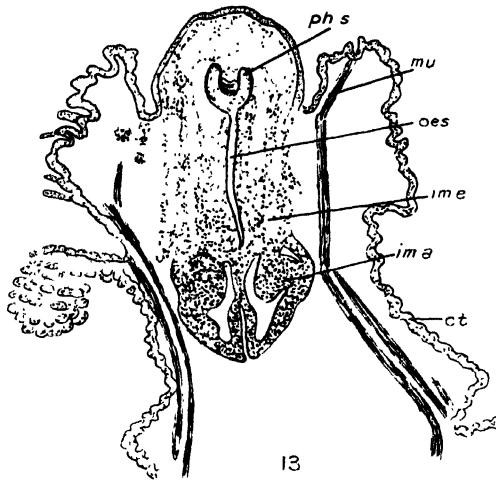
- Fig. 34. The fat-body. Dorsal view. $\times 8$.
 35. Transverse section through the prothoracic segment. $\times 285$.
 36. Transverse section through the abdomen, showing the somata. Muscles, $\times 75$.

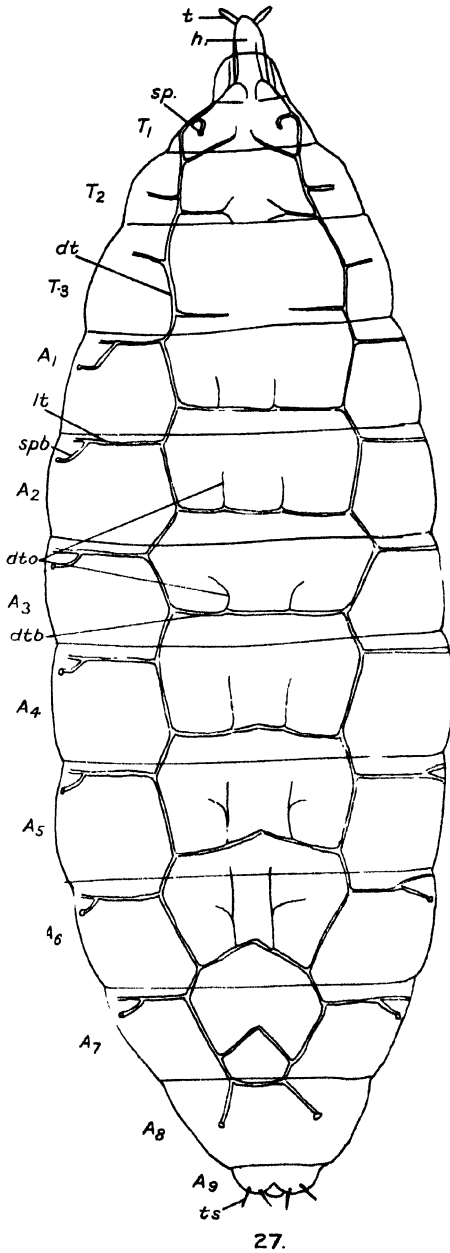


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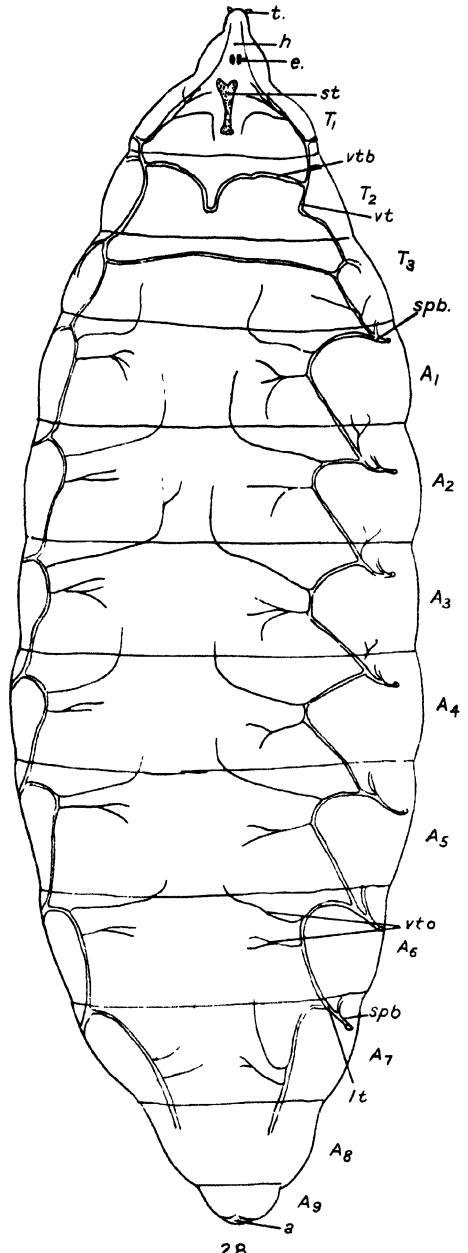


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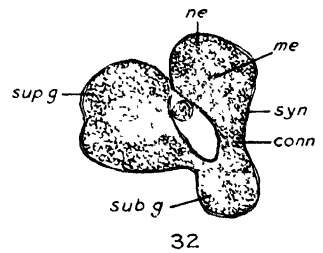
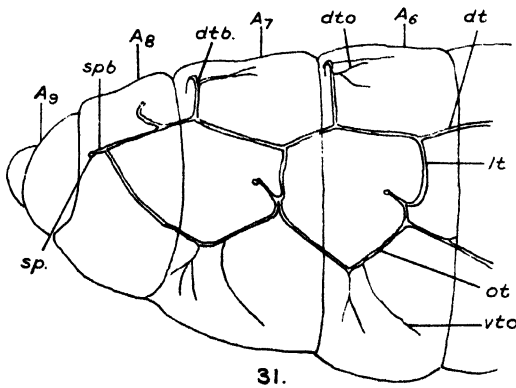
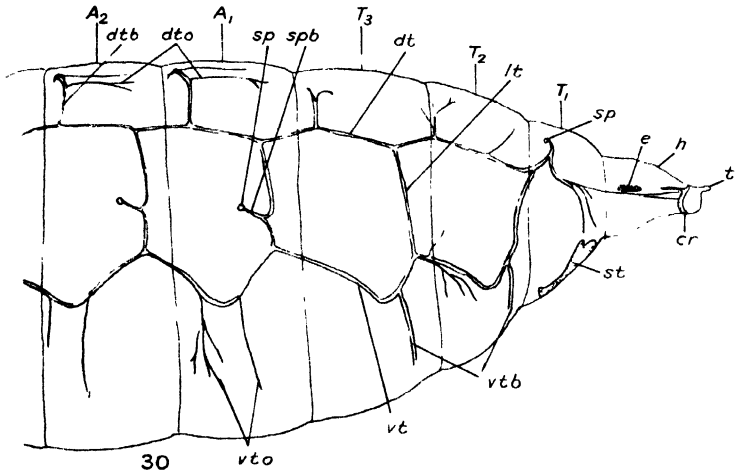
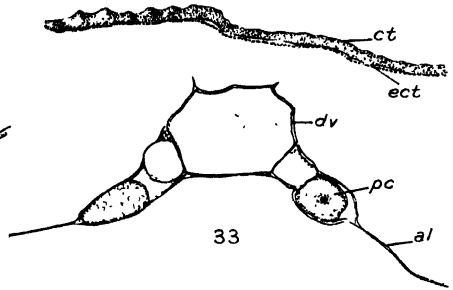
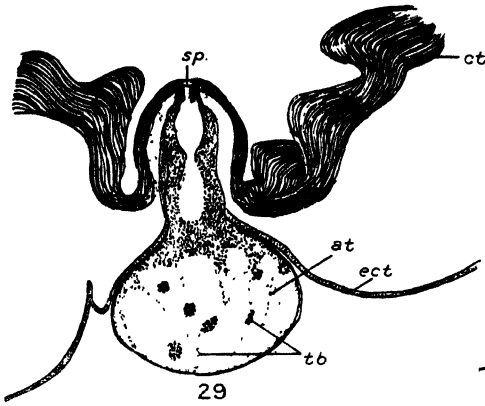


27.



28

Johnnie Sutt & D. H. Metcalfe, 1934 London





SOME CECIDOMYIDAE ATTACKING THE SEED OF *DACTYLIS GLOMERATA* L. AND *LOLIUM* *PERENNE* L.

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CONTENTS.

	PAGE
I. Introduction	327
II. Methods	328
III. Cecidomyidae attacking <i>Dactylis glomerata</i> L.	329
1. <i>Dasyneura dactylidis</i> sp.n.	329
2. <i>Contarinia dactylidis</i> (H. Lw.)	332
IV. Cecidomyidae attacking <i>Lolium perenne</i> L. .	336
<i>Contarinia lolii</i> sp.n.	336
V. Control	339
VI. Summary	340
VII. Acknowledgments	340
References	341

I. INTRODUCTION.

It has long been known that Cecidomyid larvae are responsible for damaging the grain in cereals. Similarly grasses grown for seed are subject to their attack. Information on this subject has recently been collected from scattered literature by Tomaszewski (1931) who deals with European species attacking stems as well as seed, and Barnes (1931) whose list includes species recorded from the seed only, but from all parts of the world. Three species are included by Tomaszewski which do not appear in Barnes' paper, viz. *Dasyneura airae* Kieffer on *Aira flexuosa*, *Cecidomyia poae* P. de B. on *Poa trivialis* and the larva of an unnamed species on *Phleum pratense* which Barnes refers to as only found in England.

Besides giving this list of midges already recorded Tomaszewski reported that he found Cecidomyidae attacking the seed of the following grasses on the meadows at Randowbruch [Germany]: *Aira caespitosa* L., *Calamagrostis arundinacea* Roth, *C. epigeios* L., *C. neglecta* Fr., *Phalaris arundinacea* L., *Poa pratensis* L., and *P. serotina* Ehrh. He identified the midge on the *Poa* spp. as a species of *Contarinia*, but was unable to decide for himself whether or not it was a distinct species, as it was structurally

very similar to *C. tritici* (Kirby) and *C. merceri* Barnes. The damage at Randowbruch was reported by von Oettingen (1929) to be 60–75 per cent. in a normal year, and in several years 90 per cent. of the grass seed was lost. Tomaszewski states that the loss in 1929 and 1930 was 75–80 per cent. of the crop. The damage to seed of *Alopecurus pratensis* by Cecidomyids in England has been so severe that in many cases its use has been discontinued in favour of Timothy (*Phleum pratense*) (Barnes, 1930).

It was decided to investigate whether and, if so, to what extent, Cocksfoot (*Dactylis glomerata*) and Perennial Ryegrass (*Lolium perenne*) were subject to such attacks in Great Britain. Previously to this study *Contarinia dactylidis* (H. Lw.) had been recorded from the flower heads of *D. glomerata* in Germany, and Bagnall and Harrison (1918) also had recorded Cecidomyid larvae in *D. glomerata* spikelets in Durham, England.

The three midges of which an account is given in this paper have only been under observation for a year (June 1931 to July 1932), but the main features of the life histories have been worked out in each case. The observations were made at Harpenden which is about twenty-five miles north of London.

II. METHODS.

During the first weeks of June 1931 daily inspections were made of the grasses on the Park Grass Plots at Rothamsted. Female midges were observed ovipositing on heads of *D. glomerata*, *L. perenne*, *Bromus* sp., and *Avena* sp. It was decided to study those on the first two grasses. On June 15th larvae were found, and on June 27th samples of infested heads were collected. These were placed on damp coconut fibre, protected by a lamp glass covered by muslin-covered iron rings¹. The midges emerging the following spring were used for estimating the extent of infestation and biological studies, including immunity experiments. For these, plants of *Alopecurus pratensis*, *Dactylis glomerata*, *L. perenne*, *F. rubra* var. *arenaria* were obtained and planted out of doors at the laboratory. Other grasses were also planted but did not flourish and so were not used. The plants selected for experiments were covered with muslin cages before the flowers opened, and the midges were later introduced into them. From time to time the heads were examined for eggs and for larvae in the different instars. About three weeks after the plants had been infested all the heads were cut and brought indoors. Here they were sprayed with water at intervals, and the larvae which came out were placed after examination on damp fibre in order to observe pupation. Cross-mating

¹ See Imms, A. D., Some methods of technique applicable to entomology, *Bull. Ent. Res.* (1929), **xx**, 170.

experiments on the adults were also attempted. Owing to the limited period available no attempt has been made to discover the distribution of the midges described.

III CECIDOMYIDAE ATTACKING *DACTYLIS GLOMERATA* L.

Two Cecidomyids are responsible for the destruction of seed in Cocksfoot—they are *Dasyneura dactylidis* sp.n. and *Contarinia dactylidis* (H. Lw.).

1. *DASYNEURA DACTYLIDIS* SP.N.

(a) Identification.

No *Dasyneura* has hitherto been recorded on *D. glomerata*, but three species of *Dasyneura* have been found damaging grass seed, viz. *D. airae* Kieffer, *D. alopecuri* (Reuter) and *D. graminis* Felt. The original descriptions of these species differ from *D. dactylidis* in the following particulars:

D. airae. "Antennes de 2 + 12 articles. Les deux premiers articles du funicle sont soudés ensemble; chez le mâle ils sont 1 fois $\frac{1}{2}$ aussi longs que gros, les suivants une fois et quart, le dernier un peu plus long que les précédents, largement arrondi au bout; le col du premier article n'atteint que la moitié de la longueur de ce dernier, celui du second environ les trois quarts, celui des suivants atteint presque la longueur de l'article. Parfois l'antenne se compose de 2 + 13 articles; dans ce cas le dernier article est sensiblement plus court que les précédents...."

D. alopecuri. "Taster...; erstes Glied kurz, mehr breit als lang, abgestutzt; zweites etwas $1\frac{1}{4}$ so lang als dick, drittes ein wenig länger als zweites, über die Mitte hin schwach verdickt, viertes am schlanksten und zugleich am längsten, beinahe $1\frac{1}{2}$ mal so lang wie das drittes, allmählich verjüngt, etwas spitzig...die Länge der fünf Tarsenglieder verhält sich wie $1 : 5\frac{1}{2} : 3 : 2 : 1\frac{1}{2}$...untere Lamelle ein wenig länger, lineal, am Ende ausgerandet...."

D. graminis. "Female. Length 1.5 mm. Antennae:...13 subsessile segments; terminal segment greatly produced, apparently composed of two closely fused segments, broadly rounded apically. Palpi; first segment short, stout, sub-quadrate, slightly swollen basally, the second a little longer, stouter, the third one-half longer than the second, more slender, the fourth one-half longer than the third."

I have also examined specimens of both the latter species in the Barnes collection and am satisfied that they are different species from the one on *D. glomerata* which is described below.

330 *Cecidomyiidae attacking Dactylis and Lolium*

Male. Body length: 1.5–2 mm. Antennae: 2 + 16; fuscous brown; of typical *Dasyneura* structure; length of neck of third flagellar segment two-thirds that of node, three and two-fifths times as long as broad; neck of fifth flagellar segment equal in length to node, fourth one and a half times as long as broad; flagellar segments with a distal regular whorl of setae reaching to about one-half the length of the succeeding node, and with irregular scattered setae about three times the length of the node. Face: yellow. Eyes: black. Palps: pale yellow; basal segment quadrate, second twice the length of the first, third equal in length to the second, fourth segment about two-thirds as long as the second and third together; basal segment as long as broad, second two and a half times, third three times, fourth segment five times as long as broad; sparsely setose. Thorax: dorsal region dark fuscous. Wings: hyaline; wing-veins scaled. Legs: pale yellow; clothed with dark fuscous scales. Claws: bifid; moderately curved. Empodium: rather longer than the claws. Abdomen: reddish with dorsal bands of dark fuscous scales. Genitalia: basal clasp segment stout, not swollen, with well-developed setae; terminal clasp segment stout, slightly curved; dorsal plate deeply bilobed, the lobes triangular with well-developed setae; ventral plate bilobed; harpes well developed, irregularly digitiform; style stout, longer than the ventral plate. Cotypes: Cecid. 1873–6 inclusive, deposited in the Barnes Collection.

Female. Body length: rather longer than in the male. Antennae: 2 + 12 to 2 + 14, usually 2 + 14; fuscous brown; of typical *Dasyneura* structure; neck of third flagellar segment transverse, about one-twentieth the length of the node; nodes with two regular whorls and irregular scattered setae. Ovipositor: pocket type, about twice the length of the body when extended. Otherwise similar to the male. Cotypes: Cecid. 1877–80 inclusive, deposited in the Barnes Collection.

(b) *Life history.*

On June 1st, 1931, the midges were first observed ovipositing in the field. The larvae of this brood were full grown and ready to drop to the soil for pupation by June 29th, though the last larvae did not leave these heads until August 4th. Here again, as in *D. leguminicola*, the clover seed midge, the period spent by the fourth instar larvae in the grass heads may be prolonged by about four weeks after the larva is full grown.

The midge is single-brooded in Harpenden, and in 1932 emergence took place between May 21st and June 6th with the crest of emergence on May 29th. The males appear earlier in the season than the females, the

greatest numbers of males being obtained on May 23rd and of females on May 24th. Out of 304 emergences there were 107 males and 197 females, giving a ratio of 35 males to 65 females.

Mating takes place very soon after emergence, and the females appear ready to lay their eggs immediately. Females placed on plants at about 3 p.m. (standard time) on May 30th started ovipositing immediately and egg laying was continued on the following day. The ovipositor appears to be thrust down between the paleae. Unfortunately no eggs could be found, neither were any first or second instar larvae obtained. On June 23rd, however, larvae in what appeared to be the third instar were found. These had an average measurement of 1.452×0.488 mm.; they were pale pink in colour, with the anchor process fully developed and pale yellow.

All the infested heads were brought into the laboratory on June 27th and sprayed with water: a very few full-grown larvae came out of the heads, and these, when placed on coconut fibre, went down for pupation.

This failure to raise the midge in any numbers may have been due either to the state of development of the grass heads, which after the cold and wet May were as yet unopened, or to the presence of thrips within the flowers. These insects have been said to feed upon the eggs of the clover flower midge (Pergande, 1882), and as they were present in the Cocksfoot heads in large numbers they may have been responsible for the destruction of many eggs.

(c) *Damage.*

The damage is done by the larva which eats away the ovary. The larvae feed singly, one larva destroying one seed, and the following tables show the infestation figures on Park Grass Plots in 1931:

Sample no.	No. of grass heads	No. of larvae	Average larvae per head
1	30	71	2.4
2	30	31	1.03
3	30	13	0.43
4	30	4	0.13
5	50	35	0.70
6	58	30	0.50
7	108	69	0.64
8	144	96	0.66

This gives an infestation of slightly less than one larva per head of grass.

In addition, samples, each of 30 heads of Cocksfoot, were placed on coconut fibre. The adults and parasites which emerged in 1932 give the following infestation:

332 *Cecidomyidae attacking Dactylis and Lolium*

Sample (30 heads each)	♂♂	♀♀	Para- sites	Average parasitism	Total emergences	Average per head
CFA	9	15	20	45%	44	1.46
CFB	10	15	18	42	43	1.43
CFC	11	10	31	60	52	1.73
CFD	5	3	16	66	24	0.80
CFE	3	4	16	66	23	0.76
CFF	29	37	14	17.5	80	2.66
CFG	12	38	56	53	106	3.53

Supposing each parasite destroys one midge larva, these figures would indicate that, on the average, slightly below two seeds in each head were destroyed.

An infestation of from 0.13 to 3.53 per head cannot be considered serious since a head of Cocksfoot may contain from 500 to 1500 flowers. The damage to Park Grass is therefore at present negligible, but the latent possibilities of such a pest cannot be ignored.

(d) *Parasitism.*

Parasitism of the 1931 brood ranged from 17.5 per cent. in Sample CFF to 66 per cent. in Sample CFE, with an average of 42.3 per cent. for the seven samples: this would not in itself constitute an effective control in a year of heavy infestation. The parasite is *Prosactogaster tisis* Walk.¹ [Scelionidae]. The parasites hatched between April 22nd and June 5th, with a crest of emergence on May 30th, one day after that of the midges.

2. *CONTARINIA DACTYLIDIS* (H. Lw.).

(a) *Identification.*

A Cecidomyid on *Dactylis glomerata* has already been recorded as *C. dactylidis* (H. Lw.). Loew's original description (1851) of this midge deals with the female only, and, as far as it goes, the *Contarinia* found on *D. glomerata* on the Park Grass Plots agrees with this description. Five other species of *Contarinia* are responsible for seed damage: *C. merceri* Barnes, *C. arrhenatheri* Kieffer, *C. avenae* Kieffer, *C. brizae* Kieffer, and an unnamed species on *Poa trivialis* described by Tomaszewski.

The following features distinguish these Cecids from *C. dactylidis*:

C. merceri. "Male. Body length 1-2 mm.;...the stem and neck of the third flagellar segment two or three times as long as broad, those of the tenth three to four times as long as broad..."

C. avenae. "Palpes de quatre articles qui sont, du premier au dernier, 1½, 2½, 3 et 5 fois aussi longs que gros...chez les femelles, les articles

¹ Kindly identified by Dr Ferrière of the Imperial Institute of Entomology.

inférieurs (des antennes) un peu rétrécis au milieu; le premier article est cinq fois aussi long que gros, et le col a le septième de sa longueur; le second et le troisième subégaux, deux fois et un tiers aussi longs que gros, avec un col qui atteint le tiers de leur longueur; les suivants deux fois aussi longs que gros, le col atteint la moitié de leur longueur, à l'exception des deux derniers articles, où il n'atteint plus que le tiers...."

C. arrhenatheri. "Femelle...les articles des palpes sont $1\frac{1}{2}$, 2, $3\frac{1}{2}$ et 4 fois aussi longs que gros...."

C. brizae. "...Rückenschild mit drei schwarzen Längstreifen. Hinterleib roth, mit dunkeln Querbinden...."

Contarinia sp. on *Poa trivialis*. "Weibchen...Gliederstiele ca. $\frac{1}{3}$ so lang wie die Geisselglieder. Längenverhältniss der Geisselglieder: I = 1.25; II = 0.85; III = 0.60; IV = 0.65; V = 0.60; VI = 0.70; VII = 0.65; VIII = 0.68; IX = 0.65; X = 0.70; XI = 0.70; XII (mit Griffel) = 1.0."

It is therefore considered that the species dealt with is identical with *C. dactylidis* (H. Lw.), an amplified description of which is given below:

Male. Body length 1-1.5 mm. Antennae: 2 + 12; fuscous brown; of typical *Contarinia* structure; basal and distal nodes of third flagellar segment about equal in size; stem and neck of third flagellar segment about equal in length and about three times as long as broad; stem about one and a half times as long as the basal node; stem and neck of tenth flagellar segment four to six times as long as broad; distal elongation of twelfth flagellar segment about half the length of the stem; each node with a whorl of six looped regular circumfila, arising distally and approximately equalling in length the stem or neck; each node also with a whorl of regular setae about one and a half times the length of the circumfila. Palps: pale yellow; sparsely setose; basal segment quadrate, second one and three-quarters times as long as the first, third two and a quarter times as long as the first, fourth segment about two and seven-eighths as long as the first; basal palpal segment about one and three-sevenths times as long as broad, second twice as long as broad, third three and two-fifths, and distal four and four-sevenths times as long as broad. Face: fuscous. Eyes: black. Thorax: fuscous brown dorsally, pleura yellow. Wings: hyaline. Legs: yellow with fuscous hairs. Abdomen: clear yellow. Empodium: equal in length to simple claws. Genitalia: basal clasp segment fuscous yellow, with long setae; distal clasp segment fuscous brown without setae; dorsal plate deeply bilobed, the lobes rounded; ventral plate deeply bilobed; style rounded, rather longer than ventral plate. Cecid. 1881-4 inclusive, deposited in the Barnes Collection.

334 *Cecidomyiidae attacking Dactylis and Lolium*

Female. Body length: rather longer than in the male. Antennae: 2 + 12; of typical *Contarinia* structure; first flagellar segment about one and a half times as long as the second, five times as long as broad, five times as long as the neck; third flagellar segment two and one-third times as long as broad, three and three-fifths times as long as the neck. Palps: basal segment quadrate, second one and one-fifth times, third one and one-seventh times, fourth segment two and three-tenths times the length of the basal segment; basal segment one and two-thirds times as long as broad, second one and a half, third two and five-sixths, fourth segment four and four-fifths times as long as broad. Wings: hyaline. Abdomen: bright yellow. Ovipositor: aciculate, very long and slender. Otherwise similar to the male. Cecid. 1895-8 inclusive, deposited in the Barnes Collection.

(b) *Life history.*

The midge was bred out in 1932 from the same heads of Cocksfoot as *Dasyneura dactylidis*. Emergence began on June 3rd, reached its maximum on June 11th and ended on June 24th, thus overlapping the brood of *Dasyneura* by four days. The males emerged rather earlier in the season than the females, but reached their crest of emergence on the same day, subsequently falling off in numbers very rapidly. The sex ratio was 34 : 66, 172 males and 339 females being reared.

Cocksfoot plants were infested with fertilised females on June 9th, 10th and 11th, but careful searching failed to reveal either eggs or young larvae. On July 1st all the heads were cut and brought indoors, where they were sprayed with water. A few larvae whose average measurements were 1.428×0.444 mm. left the heads. These, when placed on fibre, went down for pupation. The grass heads were again sprayed on July 6th when a few more larvae came out. The larvae, therefore, appear to be full grown, or at least ready for pupation, about three weeks after the eggs have been laid. In samples collected in 1931, larvae remained in the heads until August 4th. There thus appears to be a similar lengthening of the time spent as fully grown larvae in the grass heads, as occurs in *D. dactylidis*.

(c) *Damage and infestation.*

The damage is done by the larvae which feed collectively, five or six to the flower, on the ovary. The following numbers of larvae were obtained from samples taken from the Park Grass Plots in 1931. These samples were also used for the counts of *Dasyneura* larvae.

Sample no.	No. of grass heads	No. of Larvae	Average larvae per head
1	30	1	0.03
2	30	0	0.00
3	30	72	2.40
4	30	12	0.40
5	50	1146	22.90
6	58	1129	19.40
7	108	740	6.80
8	144	441	3.00

The infestation therefore ranged up to 22.9 larvae per head with an average of 6.86.

From the samples of 30 heads kept over winter the following midges and parasites were bred out in the spring of 1932:

Sample (30 heads each)	♂♂	♀♀	Parasites	Average parasitism	Total emergence	Average per head
CFA	31	60	22	19%	113	3.76
CFB	39	68	15	12	122	4.06
CFC	46	68	13	10	127	4.23
CFD	5	17	8	27	30	1.00
CFE	9	9	0	0	18	0.60
CFF	4	17	0	0	21	0.70
CFG	4	9	2	13	15	0.50

It will be observed that probably fewer larvae of this species came to maturity than in the case of *D. dactylidis*.

The average infestation in both larval and adult counts is very low, even where the larvae averaged 22.9 per head of grass. Since feeding is collective, probably not more than four or five ovaries would be destroyed.

(d) *Parasitism.*

Parasitism is generally lower than in *D. dactylidis*, and in the brood of 1932 the average was only 11.6 per cent. The crest of parasites coincided with the maximum numbers of midges emerging. The parasite again is *P. tisia* Walk.

(e) *Immunity trials.*

Attempts were made to infest *Festuca rubra* var. *arenaria* and *L. perenne* with *Contarinia dactylidis*.

Three weeks were allowed to elapse after the time of infestation, then the heads were cut, brought indoors and sprayed with water. This was repeated at intervals of five days, but no larvae were obtained. *F. rubra* var. *arenaria* and *L. perenne* may therefore be considered not subject to attack from *C. dactylidis*. This provides additional evidence to show that the *Contarinia* found on *L. perenne* is a distinct species. Cross-mating experiments were tried with these two midges, but with no success.

IV. CECIDOMYIDAE ATTACKING *LOLIUM PERENNE* L.

No Cecidomyid has previously been recorded from *L. perenne*, and the species herein noted is described as a new species of *Contarinia*, viz. *C. lolii*. It differs in the following features from the other *Contarinia* found damaging grass seed:

C. merceri. "♂ Circumfila in 7-9 regular loops. Stem and neck of third flagellar segment about two to three times as long as broad, those of tenth three to four times as long as broad."

C. avenae. "♂ Antennes: les quatre premiers cols sont un peu plus courts que leur nodosité; ceux des suivants un peu plus longs qu'elle; celui de la nodosité globuleuse, toujours plus long que celui de la nodosité ovulaire; le col de la nodosité terminale égale la moitié de la longueur de celle-ci."

"♀ Chez la femelle, le premier article est cinq fois aussi long que gros, et le col a le septième de sa longueur; le second et le troisième subégaux, deux fois et un tiers aussi longs que gros, avec un col qui atteint le tiers de leur longueur; les suivants deux fois aussi longs que gros, le col atteint la moitié de leur longueur, à l'exception des deux derniers articles, où il n'atteint plus que le tiers. Oeufs blancs."

C. arrhenatheri. "♀ les articles des palpes sont $1\frac{1}{2}$, 2, $3\frac{1}{2}$ et 4 fois aussi longs que gros."

C. brizae. "Hinterleib roth, mit dunkeln Querbinden."

Contarinia sp. on *Poa trivialis*. "♀ Gliederstiele ca. $\frac{1}{3}$ so lang wie die Geisselglieder. Längenverhältniss der Geisselglieder: I = 1.25; II = 0.85; III = 0.60; IV = 0.65; V = 0.60; VI = 0.70; VII = 0.65; VIII = 0.68; IX = 0.65; X = 0.70; XI = 0.70; XII (mit Griffel) = 1.0."

C. dactylidis. "♂ Palps: basal segment quadrate; second segment $1\frac{1}{4}$, third segment $2\frac{1}{4}$, fourth segment $2\frac{1}{8}$ times the basal segment."

The features distinguishing one species from another are clearly minor characters and cannot always be relied upon for the satisfactory separation of two species: the only reliable method at present is to attempt mating experiments. Thus while *C. dactylidis* differs from *C. lolii* only in proportion of the palp segments, the cross-mating experiment failed completely.

CONTARINIA LOLII SP.N.(a) *Description.*

Male. Body length: 1-1.5 mm. Antennae: 2 + 12; fuscous brown; of typical *Contarinia* structure; nodes of third flagellar segment approximately equal in size; stem and neck approximately equal in length; stem

about one and one-third the length of basal node; stem about three to three and a half times as long as broad; stem and neck of tenth segment from four to six times as long as broad; distal prolongation of twelfth flagellar segment about five-sixths of stem; each node with an apical whorl of six regular, looped circumfila, those of basal node about equal in length to the stem, those of distal node about two-thirds the length of the neck. Palps: fuscous; second segment one and one-sixth as long as first, third one and two-thirds, fourth one and five-sixths as long as first; basal segment twice as long as broad, second one and three-fifths, third two and three-quarters, fourth segment five times as long as broad; sparsely setose. Face: fuscous. Eyes black. Thorax: fuscous yellow with a darker band dorsally. Wings: hyaline. Legs: yellow with fuscous scales. Claws: simple. Empodium: rather shorter than the claws. Abdomen: clear yellow. Genitalia: basal clasp segment swollen, with long setae; distal clasp segment fuscous; dorsal plate bilobed, the lobes rounded; ventral plate deeply bilobed, the lobes triangular, rounded apically; style about the same length as the ventral plate. Cotypes: Cecid. 1893-6 inclusive, deposited in the Barnes Collection.

Female. Body length: rather longer than in the male. Antennae: 2+12; of typical *Contarinia* structure; first flagellar segment one and two-thirds as long as second, five times as long as broad; node of third flagellar segment twice as long as broad, two and three-fifths as long as stem. Palps: basal segment twice as long as broad, second one and three-fifths, third three times, fourth three and three-quarters times as long as broad; second segment one and a half times as long as first, third one and seven-eighths times, fourth two and a half times as long as first. Abdomen: bright yellow. Ovipositor: aciculate, very long and slender. Otherwise similar to the male. Cotypes: Cecid. 1889-92 inclusive, deposited in the Barnes Collection.

(b) *Life history.*

C. lolii is single-brooded at Harpenden, the adult midges being on the wing in June, and the larvae overwintering in the soil. In 1932 the first midges appeared on May 31st and the last on June 26th, the crest of emergence being on June 11th. The greatest number of males emerged on June 11th, and of females on June 12th. Of the 3095 adults obtained, 882 were males, 2213 were females, the sex ratio being 28.5 : 71.5. Emergence takes place between about 6.30 a.m.¹ (standard time) and 7.30 p.m., the greatest numbers (70-93 per cent.) appearing between 6.30

¹ All times given are Greenwich standard time.

338 *Cecidomyiidae attacking Dactylis and Lolium*

and 11 a.m. The males emerge rather earlier than the females, about 33 per cent. of the males hatching before 7 a.m. as against 0.5 per cent. of the females. From 7 a.m. to 9 a.m. is the most favourable time for both sexes. Occasionally there is a second minor crest of emergence between 2 p.m. and 7.30 p.m., which is composed chiefly of males. The eggs are laid between the palae in groups of from one to five. They are a clear shiny yellow and are provided with a pedicel about two-thirds the length of the egg. Without the pedicel the eggs average 0.2608×0.0514 mm. The egg stage appears to last about six days and first stage larvae were obtained on June 15th from eggs laid on June 10th.

Further larvae were obtained from these plants on June 20th and then appeared to be in the second instar. Their average measurements were 0.6832×0.2237 mm. On June 25th larvae were found on a plant which had been infested on June 2nd. Their average measurement was 1.5238×0.4476 mm., and when placed on coconut fibre they went down for pupation.

On July 1st all the heads of infested grasses were cut and brought indoors. They were sprayed with water on July 4th when numerous larvae dropped out. The size of those leaving the plants which had been infested on June 3rd averaged 1.3800×0.4204 mm., while the larvae from plants infested on June 8th and 9th averaged 1.5238×0.3714 mm. All were ready for descending to the soil.

The spraying was repeated on July 9th, when a few more larvae dropped.

The larval period in the inflorescence is therefore from twenty-three to thirty days and may apparently be extended as in the case of *Dasyneura leguminicola*, *D. dactylidis* and *Contarinia dactylidis*.

(c) *Damage and infestation.*

The larvae feed collectively on the ovary which may be quite eaten away by their attack. From samples of heads brought in from the Park Grass Plots in 1931 the following midges and parasites were bred out in 1932:

Samples of 100 heads each	♂♂	♀♀	Parasites	Total	Average per head
RA	151	351	5	507	5.02
RB	41	160	1	202	2.02
RC	154	298	3	455	4.55
RD	132	495	9	636	6.36
RE	235	536	0	771	7.71
RF	143	266	0	409	4.09
RG	14	46	0	60	0.60
Average					4.33

The infestation is seen to range from 0.60 to 7.71 per head, with an average of 4.33. This again, as the larvae feed collectively, cannot be considered heavy damage since there may be from 120 to 200 flowers in a spike.

(d) *Parasitism.*

Parasitism was extremely low in the 1932 brood, being only 0.75 per cent. (23 parasites—3095 midges), and it is probable that a heavier attack by the midge will be evident in subsequent years. The crest of parasites was on June 3rd, eight days before that of the midges. The parasites involved have been identified by Dr Ferrière as *Inostemma boscii* Jur. [Scelionidae] and a species of Chalcididae.

(e) *Immunity.*

Immunity trials were set up with *Dactylis glomerata*, *F. rubra* var. *arenaria*, and *Alopecurus pratensis*.

The plants were infested with successive batches of midges on June 6th, 7th and 10th. Altogether *D. glomerata* received forty-three females, *F. rubra* thirty-three females and *Alopecurus pratensis* thirty-five females. The heads were all cut on July 1st and brought indoors. They were then sprayed with water at intervals of about four days. No larvae left the heads, and the three species are therefore considered not subject to attack by *C. lolii*.

V. CONTROL.

Hitherto, no record has been made by seed growers in England that the three grass midges described above are responsible for any serious damage. At Harpenden, the combined attack of *Dasyneura dactylidis* and *Contarinia dactylidis* upon Cocksfoot in 1931 was only responsible for the loss of about 0.6 per cent. of the seed. Parasitism in *D. dactylidis* averaged 42.3 per cent., in *C. dactylidis* 11.6 per cent. and in *C. lolii* only 0.75 per cent. in 1932. There are no data to show whether parasitism is on the increase or decrease but it is very low in the case of the two *Contarinia*. It is unfortunate that these observations, begun in 1931, cannot be continued over the next two years, so that it could be estimated whether the pests were increasing or not.

A successful method of combating the attacks of Cecidomyids is to control the period of susceptibility in the host plant so that it has already been passed, or has not yet been reached when the flight of midges is at its maximum. Early cutting of the first crop of clover is advocated so that the second crop may be free from attack (Creel and Rockwood, 1918). Barnes (1930) suggests that grazing of grass fields by sheep so as to

prevent the flowering of the grass until after the crest of emergence of midges as a means of control for *D. alopecuri*, *C. merceri* and *Stenodiplosis geniculati* on *Alopecurus pratensis*. Tomaszewski (1931) states that the grass should be cut from two to three days after the crest of emergence of the midges, and should then be dried and carted with all possible speed. This has the effect of killing the larvae in the very young stages and so diminishes the numbers of the overwintering brood. Both these methods might be applied with success to the control of the Cecidomyids on *Dactylis glomerata* and *L. perenne*.

VI. SUMMARY.

1. Three species of Cecidomyidae have been observed destroying grass seed on the Park Grass Plots at Harpenden: two species attacking *Dactylis glomerata*, and the third *L. perenne*. Of the two species on *D. glomerata* one has been identified as *Contarinia dactylidis* (H. Lw.), the other is described for the first time as *Dasyneura dactylidis* sp.n. The species present on *L. perenne* is also a new species and is described as *C. lolii* sp.n.

2. All three species of midges are single brooded at Harpenden, the larvae overwintering in the soil. *D. dactylidis* emerges between May 21st and June 6th, *C. dactylidis* between June 3rd and 24th and *C. lolii* between May 31st and June 26th. The damage is done by the larvae which feed on the ovary, singly in the case of *D. dactylidis*, collectively in the other two cases. Parasitism by certain Hymenoptera in 1932 was respectively 42·3, 11·6 and 0·75 per cent.

3. It has not been found possible to cause attack by *C. dactylidis* on *F. rubra* or *L. perenne*. Similarly no infestation by *C. lolii* was produced on *F. rubra*, *Dactylis glomerata* or *Alopecurus pratensis*. It appears probable that these gall midges are specific in their attack.

4. In a brief discussion of control methods it is suggested that delaying the flowering of the grasses either by grazing sheep or by clipping, or by very early cutting to prevent the development of young larvae, might prove effective.

VII. ACKNOWLEDGMENTS.

The work was carried out at the suggestion of Dr H. F. Barnes of the Rothamsted Experimental Station who very kindly placed his collection of literature and gall midges, including types, at my disposal. Prof. Stapledon of the Welsh Plant Breeding Station and Messrs Sutton and Sons of Reading have kindly supplied the grass plants for experiments.

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Owing to the recent publication of Tomaszewski's and Barnes' compilations which contain complete references to the literature on the subject, it is considered sufficient to refer to these papers with a few additional references not given by them:

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(Received August 3rd, 1932.)

[*Reprinted from the Journal of Animal Ecology,*
Vol. II. No. 1. May, 1933.]
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STUDIES OF FLUCTUATIONS IN INSECT POPULATIONS

II. THE INFESTATION OF MEADOW FOXTAIL GRASS (*ALOPECURUS PRATENSIS*) BY THE GALL MIDGE *DASYNEURA ALOPECURI* (REUTER) (CECIDOMYIDAE)

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CONTENTS.

	PAGE
I. Introduction	98
II. Methods	100
III. Identification and biology	100
IV. Degree of infestation of the grass	101
V. Degree of relative parasitism of the midge	103
(i) Identification	103
(ii) Methods and results	103
VI. Emergence	104
VII. Sex ratio of <i>D. alopecuri</i> (Reuter)	107
VIII. Summary	108
IX. Acknowledgments	108
References	108

I. INTRODUCTION.

BEFORE going any further it may be as well to state again the object of these studies. It is primarily to collect information regarding periodic fluctuations as they occur in nature and, secondly, to provide hints of the factors involved. Subsidiary studies based upon the latter are intended to accompany the main work. The third of these, "A study of the segmentation of the antennae in gall midges," has recently been published (5). In this it was shown that in some species and genera food affects the size of the adult midge only; and that in others it affects the size of the adult midges and, in addition, the number of antennal segments. The ultimate aim of the whole project is to enable one to predict outbreaks of insect pests. This can only be done when, having developed suitable technique for studying such phenomena, one knows the manner in which the insect population varies from time to time and the causes of such fluctuations.

The first study (4) in this series dealt with the wheat blossom midges as they occurred over the period 1927-31 in a field (Broadbalk) of permanent wheat. It was shown that there were certain fluctuations during this period both in the degree of infestation of the wheat by the larvae and in the degree of parasitism. Further, it was obvious that the technique employed required

amplification and modification in certain respects. Owing to the interesting results which had already appeared, e.g. a possible periodicity in fluctuations (6), it was decided to continue this particular study for a further period of five years. Full discussion of the results was held over until other similar studies had been made.

The present paper deals with the infestation of wild Meadow Foxtail grass (*Alopecurus pratensis*) by the gall midge *Dasyneura alopecuri* (Reuter). This study resembles the previous one in that the same three aspects have been taken into consideration, viz. the degree of infestation of the crop, the degree of parasitism and the dates of emergence of the adults. Further, the period during which the work has been in progress has been practically the same, 1927-32.

The method of taking samples of wild populations, in the fully fed larval stage and of rearing the adults in an outdoor insectary, has also been nearly identical. However, instead of extracting the larvae from the plant and placing them in lamp glasses over pots containing fibre and soil, the grass heads containing the larvae have been placed in lamp glasses over pots containing soil alone. This is merely an item of breeding technique; in cases where the larvae normally leave their host plant to winter in the soil, fibre is used on account of its non-moulding and its good retention of moisture; in cases where the larvae remain in their host plant and where the particular part of the plant which contains the larvae normally falls to the ground, e.g. grass seeds or florets, the material is placed on soil alone.

There is one other important difference in this study compared with the former one which should be pointed out here. The samples of grass have been collected near Aberdeen in July and August and then kept at Harpenden throughout the following winter, spring and early summer. Thus the midges have spent the adult, the egg stage and the growth period of the larvae under the climatic and other environmental conditions pertaining to the Aberdeen district. The developmental period of the larvae and the pupal stage has been spent under Harpenden conditions. In the previous study the whole life of the midges was spent under Harpenden conditions, first on Rothamsted farm and then in the insectary at Harpenden. One effect of this change of climatic conditions has been shown (1) to cause the emergence of the midges at the normal time of that locality in which they have been kept since becoming full grown, i.e. the Aberdeen midges will emerge at the normal date for Harpenden, not Aberdeen. This, however, only holds good when the time spent in the new locality is considerable. For example, samples of grass containing the summer brood of *Stenodiplosis geniculati* Reuter, another Meadow Foxtail grass midge, when brought from different counties, emerged at dates presumably corresponding to those of the various localities (*loc. cit.* p. 352). This was owing to the fact that they were only in the new locality (Harpenden) for a few weeks.

The object in obtaining the sample from Aberdeen was twofold. Firstly, the foxtail grass at Aberdeen had been found to contain the larvae of *D. alopecuri* alone, if collected at the end of July or early August, and so the samples would not be contaminated by either of the other two Meadow Foxtail midges, *Contarinia merceri* Barnes and *Stenodiplosis geniculati* Reuter. Secondly, it was desired to see whether it would be possible for headquarters to instruct satisfactorily persons at outside centres when and how to collect samples and send them in to the centre of operations. If no untoward difficulties arose either owing to the administration or to the effect on the insects, such a procedure would increase enormously the scope of the main study.

II. METHODS.

Owing to the kindly co-operation of Dr Guy Morison, who collected the samples at specified dates, the material was obtained from two spots, only a few miles apart, along the Aberdeen—Newburgh road in late July and early August. This period was fixed for two reasons: firstly, by that date any *Contarinia merceri* larvae would have left the grass heads for the soil and so, no *Stenodiplosis geniculati* being known to occur in that locality, the sample would contain only the one species of midge it was desired to study; the second reason was that by that date the midge larvae should have finished their actual growth period.

Samples of roughly 100 heads of wild hedgerow Meadow Foxtail grass were collected and sent to Rothamsted. Here the packages were opened and if the florets were still on the heads, 100 heads were counted out and placed in a lamp glass over a pot containing soil. If, on the other hand, the florets owing to ripeness or dryness had fallen off the stems by time the packages had arrived, the whole sample was put direct into the breeding cage, merely noting how many heads had been put in. The breeding cages were then placed in the outdoor insectary on the same shelf as all the other material used in this series of studies.

In the following early summer the midges and their parasites were collected and counted, day by day, as they emerged. In this way the following data have been obtained: (1) the degree of infestation of the crop from year to year, (2) the degree of relative parasitism, and (3) the comparative dates of emergence. The method is simple and could be carried out by any one with very little practice.

III. IDENTIFICATION AND BIOLOGY.

In most districts in Great Britain three species of gall midges are to be found in the heads of Meadow Foxtail grass. Keys for their separation are included in a recent paper on their biology (1). There is no need to repeat here any more than a very brief résumé of the life history of the particular midge in question.

Dasyneura alopecuri (Reuter) has normally only one brood a year (certainly only one in Aberdeen), the adults being on the wing from late April till the third week in July, the maximum numbers occurring from about May 28th to June 17th. Eggs are laid very soon after emergence and the larval growth period usually is completed towards the end of July, i.e. by time the florets of the grass start falling to the ground. The fully grown larvae remain in the seed cases on the ground as developing larvae until the following May when pupation, quickly followed by emergence, takes place.

IV. DEGREE OF INFESTATION OF THE GRASS.

In contrast to the previous study on the wheat blossom midges where the degree of infestation of the crop was based on actual counts of the numbers of larvae present in 500 ears of wheat, it was decided in this case to calculate the infestation by the number of midges and parasites emerging the subsequent year. These figures, when corrected to allow for mortality, due to faulty technique in breeding during the winter months, should give a fairly accurate figure for the infestation. It had been found previously (1) that 75-84 per cent. emergence of midges took place when the samples were kept in the insectary. Supposing, therefore, that the observed figure of midges and parasites was 80 per cent. of the total present, we can estimate the total infestation of larvae the previous year. It is presumed that one parasite only comes to maturity out of each midge larva and also that the mortality due to faulty breeding technique would be the same each winter. As one larva destroys one seed we know how many seeds are destroyed, and if we know the average number of seeds or florets per head of grass we could calculate the percentage seed lost. From previous work it is known that on the average 287 florets occur in each ear of grass in the particular Aberdeen locality. Supposing seven of these florets would normally (and quite apart from midge attack) remain blind and fail to produce seed, we get the figure of 28,000 seeds for 100 heads of grass.

Table I shows the degree of infestation in the two localities over the period studied worked out on this basis.

The first year written in the first column indicates the year the sample was picked, i.e. the year the damage was done, and the second year in the same column means the year the midges emerged as adults and were ready to start a new infestation.

It will be seen at a glance that in the summer of 1928 there was the largest attack recorded, 22-35 per cent. of the seed being lost. At the same time the proportion of midges reaching maturity the following year (1929) compared with the number of parasites was extraordinarily high. At locality A the number of midges had increased at least threefold, while the number of parasites had decreased more than eightfold. A suggested explanation for these changes is given later on in this paper in section VI, "Emergence." In

Table I. *Degree of infestation of Meadow Foxtail grass in two localities (A and B) near Aberdeen, 1927-31.*

Year	Number of midges emerged from 100 heads of grass	Number of parasites emerged from 100 heads of grass	Total emergence	Total infesta- tion = seeds lost in 100 heads of grass (estimate)	% crop lost (estimate)
Locality A.					
1927-28	1498	924	2422	3028	11
1928-29	4748	114	4862	6078	22
1929-30	1366	312	1678	2098	7
1930-31 (i)	727	328	1055	1319	5
(ii)	1202	339	1541	1926	7
1931-32 (i)	1076	33	1109	1386	5
(ii)	1355	43	1398	1748	6
Locality B.					
1927-28	—	—	—	—	—
1928-29	7565	216	7781	9726	35
1929-30 (i)	2540	16	2556	3195	11
(ii)	1090	12	1111	1389	5
(iii)	885	4	889	1111	4
1930-31 (i)	1892	74	1966	2458	9
(ii)	2016	121	2137	2671	9½
(iii)	2122	127	2249	2811	10
1931-32 (i)	1484	26	1510	1888	7
(ii)	1539	13	1552	1940	7

spite, however, of this great number of midges on the wing in 1929, the damage done that year was only about 7 per cent. As these calculations are based on the numbers of insects emerging the following year and not direct larval counts, it is apparent that whatever mortality was due to climatic or biotic factors during the winter is completely masked. In this case, for instance, the progeny of the large numbers of midges on the wing in 1929 may have done a very large amount of damage, and then a harmful winter (1929-30) may have prevented the majority of these larvae emerging as adults in the summer of 1930. Incidentally the winter 1929-30 was, at Harpenden, milder than the previous one. This method of estimating the crop damage of the previous year by emergence figures of the subsequent year rather than direct larval counts is therefore untrustworthy. The emergence method, however, should give a comparative indication of what damage is to be expected in the coming season, provided of course the midges and parasites that emerge oviposit successfully and the resulting larvae feed successfully. It must be remembered that, owing to the conditions being limited under which oviposition can be carried out successfully, changes in the weather about this period are extremely important. We can test how this hypothesis works in practice roughly by comparing the figures of emergences obtained in 1929-32 for the wheat blossom midges with the damage done as estimated by direct larval counts. Table II sets this forth. There is an absence of correlation between the numbers of midges emerging and the extent of subsequent damage, e.g. the same amount of crop damage followed the emergence of 181 midges in 1929 and 1697 midges in 1930. It has been said a rough test can be made

of this hypothesis advisedly, because it has always been observed that a very much lower percentage emergence is obtained when dealing with a species whose larvae go to the soil for the winter than is the case when dealing with larvae which remain in the seed case or gall. For example, 75-84 per cent. of *D. alopecuri* emerged compared with only 15-17 per cent. of *Contarinia merceri*, a soil wintering form (1). This may be a natural occurrence or it may be due to error in breeding technique.

Table II. *Numbers of midges emerging and the subsequent crop damage as found by direct larval counts.*

Year	Number of <i>C. tritici</i> emerged	% crop damage	Number of <i>S. mosellana</i> emerged	% crop damage
1929	181	5.9	47	1.8
1930	1697	5.8	83	11.7
1931	873	6.4	88	15.0
1932	1905	4.9	110	10.5

It will be seen therefore that estimating forthcoming damage by the emergence method is attended by too many restrictions to be really feasible in practice.

V. DEGREE OF RELATIVE PARASITISM OF THE MIDGE.

(i) Identification.

Owing to the courtesy of Sir Guy Marshall, Dr Ferrière of the Imperial Institute of Entomology has identified some of the parasites. There are two species of Chalcids both belonging to the Tetrastichini, viz. *Aprostocetus caudatus* Westwood and *Tetrastichus roesellae* Nees. In addition there is one Proctotrypid Platygasterine, viz. *Prosactogaster attenuata* Hal. *T. roesellae* Nees. has been reared previously by the writer from *Dasyneura leguminicola* Lintn. Dr Ferrière tells me that all three species are supposedly primary parasites. It is hoped at a future date to go through all the tubes of parasites and find out how prevalent each species was during the five years they were under observation.

(ii) Methods and results.

The same methods as were used in the previous study on the wheat blossom midges have been applied in this case. Briefly, the infested grass heads have been put into rearing cages and, by finding the proportion of parasites emerging the subsequent year to the number of midges, a figure for relative or effective parasitism has been obtained. This is the number of parasites on the wing compared with the number of midges which will be causing the season's infestation or damage.

Table III shows the results obtained. In locality A it will be observed that there has been marked fluctuations in the extent of parasitism which has varied from 38 per cent. to just over 2 per cent., while in locality B there

have been fluctuations but not of the same magnitude. Further, whereas in locality A the parasitism went up in 1930 (2.3 to 19) in B it went down (2.7 to 0.7). But in 1931 it went up and in 1932 it went down in both localities.

A suggested explanation for the sudden drop in parasitism from 38 per cent. to just over 2 per cent. is given in the next section dealing with emergence.

Table III. *Relative parasitism figures, obtained by breeding in the insectary, of D. alopecuri in 1928-32 in two localities (A and B) near Aberdeen.*

Year	Date of sample	Samples of relative parasitism			Average
Locality A					
1928	27. vii. 27	38	—	—	38
1929	9. viii. 28	2.3	—	—	2.3*
1930	26. vii. 29	19	—	—	19
1931	30. vii. 30	31	22	—	26.5
1932	24. vii. 31	2.9	3.1	—	3
Locality B					
1929	23. vii. 28	2.9	2.5	—	2.7
1930	10. viii. 29	0.6	1.1	0.5	0.7
1931	30. vii. 30	3.8	5.7	5.6	5.3
1932	24. vii. 31	1.7	0.8	—	1.3

* This low figure is supported by similar ones obtained from samples which emerged during the winter and summer under different experimental conditions of temperature.

VI. EMERGENCE.

Some factors which affect the emergence of this midge have previously received some attention (2). It appears probable that favourable weather in May will cause emergence to start and that such emergences are closely correlated with day-to-day temperatures. On the other hand, after a certain date emergence will proceed very rapidly and the day-to-day temperatures will have less effect on the numbers.

Further, daily fluctuations in numbers emerging were shown in some cases to be very marked as regards the relative numbers of the sexes; one day perhaps would show an almost complete lack of females, another day practically only males, other days would show a marked decrease in both sexes. It was found that the factors affecting daily emergence numbers apparently do not exert their influence on both sexes to the same degree and also that such effects were not lethal but only delayed emergence.

The effects of light and temperature were also studied. The light was shown to affect the time of day of emergence and the females were more affected than the males. If the larvae were subjected to warm temperatures emergence could be made to take place throughout the winter. The effect of cold appeared to be very slight, but further experiments are still required to confirm this.

Table IV shows the dates of the actual first emergence and the peak of emergence of *D. alopecuri* in 1928-32. It must be remembered that these samples were kept in an outdoor insectary at Rothamsted from July or August immediately after gathering until emergence was completed the following

year. It will be seen at once that the range of first emergences is from May 9th to 27th (18 days), while that of the peaks is from May 26th to June 14th (19 days). Even in the same year the different samples have shown (1930) almost the same range in date of first emergence. The peak also varies considerably within the samples of some years (e.g. 1930 and 1932). Similarly the time that elapses between the first emergence and the peak varies from 8 to 33 days (from 11 to 22 days in 1930, and 8 to 15 days in 1929).

Table IV. *Dates of actual first emergence and at peak of emergence of D. alopecuri, 1928-32.*

Year	Date of first emergence	Date of peak of emergence	Days to reach the peak
1928	May 13	June 14	33
1929 (i)	" 21	" 4	15
(ii)	" 26	" 2	8
(iii)	" 26	" 7	13
1930 (i)	" 12	" 2	22
(ii)	" 27	" 6	11
(iii)	" 20	May 30	11
(iv)	" 13	" 30	18
1931 (i)	" 12	" 26	15
(ii)	" 13	" 27	15
(iii)	" 9	" 27	19
(iv)	" 16	" 29	14
(v)	" 19	" 28	10
1932 (i)	" 17	June 2	17
(ii)	" 20	" 5	17
(iii)	" 23	" 13	22
(iv)	" 23	" 12	21

It is obvious that too much reliance cannot be placed on the exact dates since there is so much variation between the different samples of any given year, in spite of the fact that the samples were all kept within a yard and a half of each other in the insectary and so under the same conditions.

The dates and figures in Table V show the weekly emergences of the midge and its parasites. The top rows of figures in each case refer to the midges, while the lower rows refer to the parasites. The peaks are italicised. It will be seen that a crest of emergence has occurred once only in the week May 21st to 27th, nine times in the week May 28th to June 3rd, four times in the week June 4th to 10th and three times in the week June 11th to 17th. Yet there is considerable variation between the different samples even in the same year, e.g. 1931 and 1932.

The emergence of the parasites also varies; once the peak occurred in the week June 4th to 10th, six times in the week June 11th to 17th, nine times in the week June 18th to 24th, and once in the week June 25th to July 1st. It is apparent that in the aggregate the crest in emergence of parasites occurs in the third week after that of the host midge. (This interval varies from 1 week to 3 weeks.) This allows sufficient time for the egg and larvae of the midge to reach the stage of development optimal for parasitisation.

Table V. *Weekly emergence of D. alopecuri and its parasites, 1928-32.*

The upper rows of figures refer to the midges, while the lower refer to the parasites.
The peaks are italicised. Asterisks mark the two halves of one sample.

Year	Size of sample (heads of grass)	May 7-13	May 14-20	May 21-27	May 28-June 3	June 4-10	June 11-17	June 18-24	June 25-July 1	July 2-8	July 9-15	July 16-22	Later	Total host and parasites	Para- sitism %
1928	106	2	1	3	187	350	708	196	110	18	13	3	1	1588	38
1929	84*	.	.	.	161	3716	422	329	12	2	1	.	.	7897	2.9
"	84*	.	.	18	4	337	69	94	44	7	.	.	.	241	2.5
"	50	.	.	48	2248	2175	183	154	5	7	1	.	.	4813	2.3
"	91	.	.	10	5	2	46	35	16	5	1	2	.	122	19
1930	105	.	.	6	553	1276	179	337	15	15	2	.	.	2374	0.6
"	105	.	.	1	1	0	6	17	15	15	.	.	.	57	1.1
"	100	.	.	241	568	347	59	3	1	.	.	.	.	1244	0.5
1931	100	.	.	.	1	15	64	145	54	4	1	.	.	284	3.8
"	100	.	.	1	80	354	64	106	5	3	.	.	.	2667	5.7
"	100	.	.	229	574	92	12	2	1	.	.	.	.	17	5.6
"	100	.	.	38	560	251	36	19	3	.	.	.	.	1154	31
"	100	.	.	412	705	752	95	27	10	.	.	.	.	885	22
"	100	.	.	4	412	752	11	43	10	.	.	.	.	1892	1.7
"	100	.	.	773	996	287	14	16	10	.	.	.	.	74	0.8
"	100	.	.	92	413	197	13	8	2	3	2	.	.	2016	2.9
"	100	.	.	2	695	351	27	12	4	.	.	.	.	121	3.1
"	100	.	.	111	6	15	55	118	41	4	.	.	.	328	3.1
"	100	.	.	106	594	569	168	37	1	1	.	.	.	1202	1.7
"	100	.	.	53	475	709	262	37	9	.	.	.	.	339	0.8
"	100	.	.	12	147	337	519	57	4	1	.	.	.	26	2.9
"	100	.	.	2	5	1	4	12	4	4	.	.	.	13	3.1
"	100	.	.	3	144	411	714	80	3	1	.	.	.	1076	3.1
"	100	.	.	2	9	1	9	9	12	.	.	.	.	33	43

In one year, however, the crest of parasites actually occurred in the week before that of the midges, viz. in 1928. We have not sufficient data to explain this, but some factor or factors may have retarded the development of the midges, while hastening that of the parasites. This alteration in relative times of emergence of host and parasites is very striking and may be a possible explanation of the very great increase of midges and lowering of the relative parasitism in the subsequent year, already referred to in sections IV and V (ii) of this paper. But a similar fall in parasitism occurred in 1932 in locality A (see Table III) when the relative periods of emergence of host and parasites had been apparently quite normal the previous year.

The greatest value of ascertaining the dates of emergence at present lies in the fact that it enables one to fix the date before which the grass must not be allowed to flower if a control is required (1). It is hoped to make a subsidiary study of the climatic conditions and try to find out whether there are correlations between emergence and any such factor. This would however appear difficult, as there is so much variation between different samples kept under identical conditions. If experiments under controlled conditions were to be set up they should indicate how the insect reacts to certain limited and specified conditions, but would we be any nearer to prediction than we are at present?

VII. SEX RATIO OF *D. ALOPECURI* (REUTER).

In a previous paper (3) it was shown that the sexes at emergence were about equal in numbers. Occasionally there was a marked diminution in the numbers of one sex, e.g. a sample from Shropshire gave a ratio of 25:75. It is proposed now to give additional figures obtained from the two Aberdeen localities during the last five years. No significant variation is shown although there is a tendency for females to be in excess.

Year	Males	Females	Sex ratio
Locality A.			
1928	806	782	51 : 49
1929 (i)	3607	4290	46 : 54
(ii)	2296	2517	48 : 52
1930	607	637	49 : 51
1931 (i)	411	316	57 : 43
(ii)	525	677	44 : 56
1932 (i)	662	822	45 : 55
(ii)	684	855	44 : 56
Locality B.			
1929	966	1408	41 : 59
1930 (i)	1236	1431	46 : 54
(ii)	498	656	43 : 57
(iii)	405	480	46 : 54
1931 (i)	709	1183	38 : 62
(ii)	795	1221	39 : 61
(iii)	1084	1038	51 : 49
1932 (i)	416	660	39 : 61
(ii)	602	753	44 : 56

VIII. SUMMARY.

1. This is the second of a series of papers in which the fluctuations of insect populations in the field are being studied.

2. The degree of infestation or intensity of attack by the larvae, the degree of parasitism and the dates of emergence (host insect and its parasites) of *Dasyneura alopecuri* (Reuter), which prevents seed production in Meadow Foxtail grass, have received attention over a period of five years. The methods used have been fully discussed.

3. It would appear possible that reversal in the relative times of emergence of host and parasites may account for sudden changes in the degree of parasitism and, subsequently, changes in the extent of damage suffered by the crop.

4. It is desired to hold over a complete discussion of the results until similar studies on other species of gall midges have been completed.

IX. ACKNOWLEDGMENTS.

I should like to thank Dr Guy Morison for supplying me with the samples of grass throughout the period of this study, Dr Ferrière who has identified the parasites, and also Dr A. D. Imms and Dr C. B. Williams who have helped me considerably by discussing the work from time to time.

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GALL MIDGES (CECIDOMYIDAE) AS ENEMIES OF MITES.

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*Entomology Department, Rothamsted Experimental Station, Harpenden, England.***1. Introduction.**

This is a third of a series of papers dealing with zoophagous gall midges of the world. The first, "Gall Midges as Enemies of Aphids," was published in 1929 (Bull. Ent. Res., xx, 1929, pp. 433-442) and the second, "Gall Midges as Enemies of the Tingidae, Psyllidae, Aleyrodidae, and Coccidae," appeared more recently (*op. cit.*, xxi, 1930, pp. 319-329).

In this paper the species of gall midges whose larvae have been reported as preying on mites are dealt with, the first reference mentioned being in each case that of the original description or record. Practically all the literature available consists of specific descriptions and little is stated about the bionomics of the species with a few exceptions. It is a matter for regret that such scant attention has been paid to this aspect of biological control, especially in view of certain statements claiming that the larvae of various gall midges are of considerable importance in the natural control of red spider. It is with a view to stimulating further research in this direction that the present paper has been compiled.

It has been thought advisable to divide the paper somewhat arbitrarily into separate sections, dealing firstly with those species of gall midges preying on free-living mites and secondly with those species preying on gall-inhabiting mites. A further section deals with those Cecidomyids which may feed on mites. As an additional convenience, a list of plants on which the mites live is appended. The Cecidomyids which may be predacious on mites (see section 5) are not, however, included in this list.

I am indebted to Mr. A. M. Massee, of the East Malling Research Station, for his kind assistance with regard to Mite nomenclature.

2. Addenda to "Gall Midges as Enemies of the Tingidae, Psyllidae, Aleyrodidae and Coccidae."

Clinodiplosis latibulorum (Winn.).

Winnertz, Linn. Ent., Stettin, viii, 1853, pp. 247-248 (*Diplosis*).

Kieffer, Genera Insectorum, fasc. 152, 1913, p. 238 (*Clinodiplosis*).

Boselli, Boll. Lab. Zool. Portici, 1928, p. 249.

This species, of which the male and female were described from Germany by Winnertz, is recorded by Boselli as attacking *Physokermes abietis* (Geoff.) in Italy.

Unknown Cecids.

P. E. Keuchenius (Meded. v. L. Besoekisch Proefstation, Djember, no. 16, 1915, p. 63; R.A.E., A, iii, 1915, p. 648) mentions a Cecidomyid as preying on *Pseudococcus bicaudatus*, Keuch., in Java. He states that it may be *Diplosis acarivora*, Zehnt., but the present writer considers this improbable.

J. C. Koningsberger and A. Zimmerman (Meded. u. 'Slands Planteum, xlv, 1901, p. 34, pl. 1, figs. 19, 20) record and figure a Cecidomyid as parasitic on *Pulvinaria psidii* in Java on coffee.

Reprinted from the BULLETIN OF ENTOMOLOGICAL RESEARCH, VOL. XXIV. Pt. 2, July, 1933.

Arthrocnodax apiphila, Felt.

This species was reared once from a twig badly infested by *Pulvinaria vitis*, Linn. For further information see *A. apiphila* in section 3 of this paper.

Schizobremia formosana, Felt.

Barnes, Ann. Mag. Nat. Hist. (10) ix, 1932, p. 478.

This species was originally reared from *Pseudococcus brevipes*, Ckll. More recently it has been reared from *P. filamentosus*, Ckll., in Formosa.

Silvestrina koebeleri, Felt.

Felt, Pan-Pacific Entomologist, viii, 1932, pp. 167-168.

Felt has now described both sexes of this midge which was mentioned in my previous paper (1930) on page 327 under *Other Gall Midges* as *Diplosis* sp.

Triommata coccotroctes, Barnes.

Barnes, Bull. Ent. Res., xxii, 1931, pp. 205-207.

Both sexes described. The adults are peculiar in possessing a dorso-median and two lateral compound eyes instead of the normal type. Reared by E. Hargreaves in 1930 from larvae preying on mealy-bug at Njala, Sierra Leone.

Olesicoccus costa-limai, Borg.

Borgmeier, Rev. de Entomologia, i, 1931, pp. 184-191.

Both sexes as well as larva and pupa described. Larvae predacious on *Pulvinaria ficus*, Hemp., in S. Paulo. Some notes on the life history are also given.

3. Gall Midges whose Larvae attack free-living Mites.*Therodiplosis persicae*, Kieffer.

Kieffer, Neue Gallmücken-Gattungen, Bitsch, 1912, p. 2; Marcellia, xi, 1912, pp. 10-11 (this is a reprint of the former, which was published separately); Genera Insectorum, fasc. 152, 1913, pp. 202-203).

Barnes, Ent. Mon. Mag., lxii, 1925, pp. 57-58.

Speyer, Nursery & Mkt. Gdn. Ind. Devpmt. Soc. Ltd., Exptl. & Res. Sta., 11th. Ann. Rept. 1925, 1926, p. 93 (*Thecodiplosis*); *op. cit.*, 12th Ann. Rept. 1926, 1927, pp. 54-55.

Male and female described very inadequately in 1912. There is a better description in *Genera Insectorum*, where it is stated that the larvae are predacious on *Tetranychus* sp. on the leaves of peach in France. In England it has been found attacking red spider (*T. telarius*) on bean and tomato at Cheshunt by Speyer and on peach at Stroud, Gloucester (H. Eltringham, 1925) and near Derby (A. Roebuck, 1925). Other records include the following:—attacking red spider on egg-plant, 1927, Cheshunt (E. R. Speyer: Barnes collection, ♂, Cecid. 851, ♂♀, Cecid. 852); red spider on Convolvulus, 1927, Turnford, Herts. (E. R. Speyer; ♂♂, Cecid. 848 and 849); and possibly specimens (♀♀, Cecid. 219 and 423) reared from larvae attacking red spider on *Arum* at Waltham Cross in 1926 received from F. W. Edwards.

Speyer (1926) states that the eggs are laid in the web spun by the mite. Pupation takes place in a white cocoon along the veins of the leaves usually on the lower surface. Speyer (1927) states that the larva is a voracious feeder on all stages of red spider in tomato houses. The larvae were first noticed in July and became more plentiful until

September, when it is too late to exert any control over the pest. Pupation takes 9 days in August. Speyer also claims that they do not seem to be killed where the foliage was sprayed with soft soap and liver of sulphur solution.

Feltiella acarivora, Tölg.

Tölg, Neue Beitr. z. syst. Insek., ii, 1921, p. 33.

Male described, but no biological data given. This paper was published posthumously.

Feltiella acarivora, Tölg.

Keiffer, in Genera Insectorum, fasc. 152, 1913, p. 202, gives Tölg, Verh. zool.-bot. Ges. Wien, lxiii, as the reference to the original description of this species, which he states is found in Austria. No trace, however, can be found of this description, but see above under *Feltiella acarivora*, Tölg.

Feltiella americana, Felt.

Felt, Canad. Ent., xlviii, 1916, pp. 33-34; N.Y. St. Mus. Bull., no. 202, 1918, p. 171.

Zool. Record, liii, 1916, Insecta, p. 217 (*Feltia*, undoubtedly a misprint).

Male and female described. Reared at the end of July 1915 by P. J. Parrott of the Agric. Exp. Sta., Geneva, N.Y., from larvae apparently feeding on red mites occurring on plum foliage.

Feltiella ithacae, Felt.

Felt, Ent. News, xxxvii, 1926, p. 141.

Male and female described. Reared in August 1925 by Grace H. Griswold of Cornell University from larvae probably predacious on red mites and other small forms upon the rose. It spins cocoons upon the leaves.

Feltiella tetranych, Rübs.

Rübsaamen, Zeits. wiss. Insektenbiol., vii, 1911, pp. 280-282.

Keiffer, Genera Insectorum, fasc. 152, 1913, p. 202.

Piontkovskii [Cotton Indust.], vii, 1928, pp. 365-370 (R.A.E., A, xvi, 1928, p. 669).

This species is the generic type. Both sexes are described and figures are given of the male genitalia, female antennae, claw and entire adult. The larvae feed on red spider, *Tetranychus*, on hops, *Humulus lupulus*. They were found in August 1895 at Berlin. From larva to adult takes from 10 to 14 days. They are preyed on by *Scymnus ater* (Coccinellid).

Piontkovskii mentions "*Feltiella (Arthrocnodax) tetranych* Rübs." as attacking an undescribed species of *Epitetranychus* on cotton in Turkestan. The mite was previously recorded as *Tetranychus telarius* he adds. It seems probable that he has made a mistake as regards the nomenclature and identity of the midge. Probably he really means *Acaroletes tetranychorum*, Kieff., which was originally called *Arthrocnodax tetranych*, Kieff., and whose larvae are predacious on *T. telarius* in S. Russia (see under *Acaroletes tetranychorum*).

Feltiella venatoria, Felt.

Felt, J. N.Y. Ent. Soc., xxv, 1917, pp. 195-196; N.Y. Mus. Bull., no. 202, 1918, pp. 172-173.

Male and female described. Received from D. K. McMillan, Northern Illinois, presumably Chicago, in August 1916. The larvae are stated to be very efficient destroyers of *T. telarius* and other species on the leaves of elm and hollyhock.

Acaroletes tetranychorum (Kieffer).

Kieffer, Revue Russe Ent. 1907, 1908, pp. 201-202 (*Arthrocnodax tetranychi*); Marcellia, xi, 1912, p. 229 (*Acaroletes tetranychi*); Genera Insectorum, fasc. 152, 1913, p. 201 (*tetranychorum* n. nov.).

Vasilev [Cotton Indust.], iii, 1924, pp. 86-116 (R.A.E., A., xii, 1924, p. 555 (*Acaroletes tetranychi*)).

Male and larva described. Received from J. Vasilev. The larvae live on *T. telarius* in S. Russia. This species was made the type of the genus *Acaroletes* by Kieffer in 1912. Vasilev states that it is abundant throughout the cotton area from Transcaucasia to Turkestan, preying on *T. telarius*. This is probably the species Piontkovskii refers to in his paper of 1928 mentioned above under *Feltiella tetranychi*, Rûbs.

Mycodiplosis acarivora (Felt).

Felt, Ent. News, xviii, 1907, p. 242 (*Cecidomyia*); N.Y. St. Mus. Bull., no. 125, 1908, p. 385, 403 (*Mycodiplosis*); Pomona Coll. J. Entom., iv, 1912, p. 756; J. Econ. Ent., vii, 1914, p. 458; N.Y. St. Mus. Bull., no. 202, 1918, pp. 201-203.

Kieffer, Genera Insectorum, fasc. 152, 1913, p. 213.

Male, female and larva described. Received from Frederick Maskew of S. California. The larvae were found feeding on *Tetranychus mytilaspidis* and *T. sexmaculatus*, infesting lemon leaves and fruit at Chula Vista, Cal.

Felt (1918) states that this species or a very closely allied form was reared from larvae attacking red spider on the Kentucky coffee tree, *Gymnocladus canadensis*, and on corn from lots sent for identification by L. O. Howard. In the same reference are given some general notes, made by Theodore Pergande in August 1883, on larvae of the same genus, and probably this species, which he found feeding on red spider on corn.

Mycodiplosis insularis, Felt.

Felt, Canad. Ent., xlv, 1913, pp. 305-306; J. Econ. Ent., vii, 1914, p. 458; N.Y. St. Mus. Bull., no. 202, 1918, p. 184.

Male, female and larva described. The larvae and white cocoons were collected at Rio Piedras, P.R., in August 1913 by Thomas H. Jones from among colonies of red spider on the leaves of *Leonotis nepetaefolia*.

Mycodiplosis macgregori, Felt.

Felt, J. Econ. Ent., viii, 1915, p. 149; N.Y. St. Mus. Bull., no. 202, 1918, p. 196.

McGregor & McDonough, U.S.D.A., Bull. 416, 1917, pp. 51-52.

Male described. It was reared by E. A. McGregor, South Carolina, from larvae attacking red spider on cotton. Apparently it resembles *A. carolina*, Felt, in general biology but appears later, even as late as December.

Mycodiplosis sp.

Larvae of this genus were found in August 1930 at Harpenden on the leaves of hollyhock, which were heavily infested with red spider and also had spots of rust on them. It is not certain whether they were feeding on the mites or rust but probably the former. Some adults were reared (♂, Cecid, 1483; ♀, Cecid, 1484; larvae, Cecid. 1617 and 1482; other specimens in alcohol tube 950).

Arthrocnodax acarisuga (Vall.).

Vallot, Mém. Acad. Sc. Dijon, 1827, pp. 95-96 (*Cecidomyia*).

Kieffer, Ann. Soc. ent. Fr., lxi, 1901, p. 333 (*Cecidomyia*); Genera Insectorum, fasc. 152, 1913, p. 156 (*Arthrocnodax*).

This the first record of a mite-eating Cecidomyid.

The larvae feed on mites (*Acarus*) on the lower side of the leaves of *Chelidonium majus* in August and September. The cocoon is to be found at the junction of the veins on the leaf.

Arthrocnodax apiphila, Felt.

Felt, New Species of Cecidomyidae II, 1907, p. 20; N.Y. St. Mus. Bull., no. 124, 1908, p. 301, 404; Pomona Coll. J. Entom., iv, 1912, p. 756; J. Econ. Ent., vii, 1914, p. 458; N.Y. St. Mus. Bull., no. 175, 1915, pl. 2, fig. 12; *op. cit.*, no. 200, 1918, p. 150; *op. cit.*, no. 231-2, 1921, pp. 81, 87-89, figs. 4-6.

Kieffer, Genera Insectorum, fasc. 152, 1913, p. 156.

The male was described in 1907 and both sexes in 1921. It was bred in October 1907 by Burton N. Gates from larvae feeding in mite-infested material and excrement of old bee combs received from California. Dr. Felt considers that they may have been feeding on a species of *Tyroglyphus* and a red mite belonging to the GAMASIDAE which were found among the material.

This species had, according to Felt (1921), also been reared from a twig badly infested by *Pulvinaria vitis*, Linn., and from a breeding jar containing forest tent caterpillar (*Malacosoma disstria*, Hübn.) cocoons and debris received from Tacoma, Wash. It was also obtained from a jar containing *Viburnum* leaves bearing numerous blister galls. He also states that possibly *Aphanogamus floridanus*, Ashmead (Insect Life, iv, 1891, p. 123) is a parasite of this species.

Arthrocnodax carolina, Felt.

Felt, J. Econ. Ent., vi, 1913, pp. 488-489; *op. cit.*, vii, 1914, p. 458; N.Y. St. Mus. Bull., no. 200, 1918, p. 171; *op. cit.*, no. 231-2, 1921, p. 90.

McGregor, J. Econ. Ent., vii, 1914, p. 330.

McGregor & McDonough, U.S.D.A., Bull. 416, 1917, pp. 48-51.

Male and female described from larvae eating red spider on cotton at Batesbury, S. Carolina, and reared in 1912 and 1913 by E. A. McGregor.

The earliest occurrence is at the end of April and it is abundant in the middle of May. It multiplies very rapidly in July and August when it is at its height of development. Then it becomes more scarce in September and is met with only occasionally in October. The larval stage lasts 3-5 days, the pupal state 8 days and the whole life-cycle is completed in 16 days.

McGregor claims that this midge occupies first rank among the enemies of red spider (*T. telarius*, L.=*bimaculatus*). The larvae confine their attack to the eggs. The time taken to suck one egg is from 1 to 2 minutes and the average egg consumption a day is 45.9, according to McGregor & McDonough (1917). Tables dealing with the life-history are also given in this paper. Later in the season the larvae are heavily parasitised by *Aphanogamus floridanus*, Ashmead, a Chalcidid.

This species has been collected from Virginia, N. and S. Carolina, Georgia, Florida, Alabama and Louisiana.

Arthrocnodax constricta, Felt.

Felt, J. Econ. Ent., vii, 1914, p. 481; N.Y. St. Mus. Bull., no. 231-2, 1921, p. 82.

Male and female described. Reared from garden beans infested with common red spider, *Tetranychus bimaculatus*. Collected by Thomas H. Jones, June 1913, at Rio Piedras, P.R.

Arthrocnodax mali, Kieffer.

Kieffer in Wissmann, Z. Pflanzenkr., xxxvi, 1926, pp. 103-104.

Wissmann, Z. Pflanzenkr., xxxvi, 1926, pp. 98-106.

Male, female, pupa and larva described, from Germany. Wissmann contributes the biological notes. The larvae are found from June to October, eating mites on apple leaves. The larval stage in August and September lasts a fortnight to three weeks, and the pupal stage about the same time. In captivity the larvae spin white cocoons on the under-surface of the leaves, but in the field such cocoons could not be found and probably pupation takes place in the soil. A *Platygaster* and a Pteromalid were reared from this species and *A. wissmanni*, Kieff., but it is not stated definitely whether from both species of midge or not.

Arthrocnodax occidentalis, Felt.

Felt, J. Econ. Ent., v, 1912, p. 402; Pomona Coll. J. Entom., iv, 1912, p. 756; J. Econ. Ent., vii, 1914, p. 458; N.Y. St. Mus. Bull., no. 231-2, 1921, p. 92.

Quayle, Calif. Agr. Expt. Sta. Bull., no. 234, 1912, pp. 514-515; J. Econ. Ent., vi, 1913, p. 87.

Ewing, Oregon Agr. Expt. Sta. Bull., no. 121, 1914, pp. 58-59.

Male only described. Ewing (1914) described the larvae and adult, and Quayle (1912) the egg and larva. Reared by H. J. Quayle from larvae feeding on *Tetranychus mytilaspidis*, *bimaculatus* and *sexmaculatus* in S. California. It is considered as one of the most important enemies of *T. telarius* on the Pacific coast.

The larvae feed chiefly on the eggs of the red spider. One larva consumed 165 spiders in 15 days, another 380 in 17 days. They are most abundant attacking *T. sexmaculatus*, probably because the latter live in definite colonies and their food is thus obtained without much moving about. The covering of web over the mites seems to afford protection to the larvae from parasites. Quayle (1912) figures an Hymenopterous parasite.

Arthrocnodax rutherfordi, Felt.

Felt, J. N.Y. Ent. Soc., xxiii, 1915, pp. 180-181.

Male only described. Reared by A. Rutherford, Royal Botanic Gardens, Peradeniya, Ceylon, in June 1914, from leaves of *Melia azedarach* infested with *Tetranychus* sp.

Arthrocnodax wissmanni, Kieffer.

Kieffer, Broteria, xxi, 1924, pp. 89-91; in Wissmann, Z. Pflanzenkr., xxxvi, 1926, pp. 102-103.

Wissmann, Z. Pflanzenkr., xxxvi, 1926, pp. 98-106.

Brooke, Entomologist, lxiv, 1931, pp. 180-182, pl. 3.

Male, female, pupa and larva described from Germany. Wissmann gives the biological notes. The eggs, which are attached to the hairs on the underside of pear and apple leaves, are long, oval and yellowish becoming reddish. A larva was seen to destroy 13 mites within 5 minutes and then go on for more. The larvae disappeared after a shower of rain. The biology is similar to that of *A. mali*, Kieffer.

This species has been found by Miss W. M. A. Brooke attacking *Phyllocoptes schlehtendali*, Nal., near the Crystal Palace, London, on the underside of the leaves

of Cellini Pippin (Phillips Seedling) apple. This is the same species of mite as Wissmann found being attacked. This author gives biological notes and states that a mite is sucked dry in 30-45 seconds, one larvae eating 9 mites in 5 minutes.

Silvestrina farinicola, Barnes.

Barnes, Bull. Ent. Res., xx, 1929, pp. 120-122; Ann. Mag. Nat. Hist., (10) ix, 1932, p. 477.

Male and female described. Reared by G. Candura from larvae found in flour at Naples. The flour was infested by mites, and it is supposed the larvae were preying on the mites.

Lestodiplosis raphani, Barnes.

Barnes, Bull. Ent. Res., xx, 1929, pp. 119-120.

Male and female described. Reared by M. Prosper Bovien, Lyngby, from larvae found among seed of radish (*Raphanus sativum*) that had been in storage and was infested by mites (*Aleurobius*, etc.). It had been found some years previously in seed infested by *Cheyletus* but in which there were no *Aleurobius*. It occurs at irregular intervals in seed from Denmark and Germany. It is presumed that the larvae were living at the expense of the mites.

This species was also sent to me in 1932 by Mr. G. Fox Wilson. He received the larvae from a correspondent who obtained it from turnip seed grown in Lincolnshire, 1930 harvest. The adult midges emerged between 6th and 22nd June 1932. The correspondent points out that they (the larvae) seem to be more prevalent in seed that is badly attacked by the flour mite. He adds "Stored seed (Brassicas) harvested after a good season and ideal conditions are rarely attacked to any extent by these pests." Mr. A. Roebuck (1932) has also sent me this species from stored radish seed at Leicester. He stated that the cocoons were to be found in large numbers on the outside of the sacks which contained seed infested with mites.

Lestodiplosis woeldickii, Contarini.

Contarini, Atti Ateneo Veneto, iii, 1839, pp. 122-130 (*Cecidomya*).

Kieffer, Bull. Soc. Hist. Nat. Metz, (2), viii, 1898, p. 40 (*Lestodiplosis*); Ann. Soc. ent. Fr., lxi, 1901, p. 333; Genera Insectorum, fasc. 152, 1913, p. 198.

Larva, male and female described and illustrated in colour. Reared from larvae found on the feathers of stuffed birds in Italy, probably feeding on mites.

Lestodiplosis sp.

Garmon, Conn. Agric. Expt. Sta. Bull., no. 225, 1921, p. 241.

Larvae of *Lestodiplosis* have been found feeding on *Rhizoglyphus hyacinthi*, Banks, in Connecticut.

Diplosis acarivora, Zehnt.

Zehntner, Arch. Java Suikerind., v, 1901, 17 pp.

Keuchenius, Meded. v. h. Besoekisch Proefstation, Djember, no. 16, 1915, p. 63 (R.A.E., A., iii, 1915, p. 648).

Dammerman, The Agricultural Zoology of the Malay Archipelago, 1929, p. 346.

It has not been possible to see Zehntner's original description. The larvae feed on *Tetranychus exsicicator* on sugar-cane leaves in Java. Keuchenius mentions a Cecidomyid as preying on *Pseudococcus bicaudatus*, Keuch., in Java and says it may be this species. The present writer thinks this improbable.

Cecid. sp.

Kieffer, Ann. Soc. ent. Fr., lxi, 1901, pp. 334-335.

Kieffer here gives a note on the larva of a gall midge which he found among mites and their dried skins on the leaves of weeping elm in August 1894.

4. Gall Midges whose Larvae are known to, or probably, attack gall-inhabiting Mites.

Arthrocnodax abdominalis, Felt.

Felt, Ent. News, xxii, 1911, pp. 128-129 (*Endaphis*); J. Econ. Ent., vii, 1914, p. 458 (*Arthrocnodax*); N.Y. St. Mus. Bull., no. 231-2, 1921, p. 85 (*Arthrocnodax*).

Kieffer, Genera Insectorum, fasc. 152, 1913, p. 155 (*Feltodiplosis*).

Male and female described. Received from C. H. T. Townsend, Piura, Peru, from cotton leaves badly infested with galls containing mites. Felt (1914) noted red spider as the prey of the larvae.

Arthrocnodax americana, Felt.

Felt, Ent. News, xxii, 1911, p. 129 (*Endaphis*); N.Y. St. Mus. Bull., no. 202, 1918, p. 92 (*Endaphis*).

Kieffer, Genera Insectorum, fasc. 152, 1913, p. 155 (*Feltodiplosis*).

Female only described. Reared in September 1910 from what appeared to be galls of *Eriophyes fraxinivorus*, Nal. (1909), on *Fraxinus velutina* collected by Dr. R. E. Kunze, Arizona, in the August. It appears that the correct generic position is as placed above.

Arthrocnodax clematidis, Marchal.

Marchal, Mém. Soc. zool. France, x, 1897, pp. 23-24.

Kieffer, Bull. Soc. Hist. nat. Metz, (2), viii, 1898, p. 29; Genera Insectorum, fasc. 152, 1913, p. 156.

Male and female described and figured. The larvae live in the galls of *Epitrimerus heterogaster*, Nal. (1890), on *Clematis cirrhosa* at Blidah, Algeria.

Arthrocnodax coryligallarum, T. T.

Targioni-Tozzetti, Bull. Soc. ent. ital., xviii, 1886, pp. 422-425 (*Diplosis*).

Kieffer, Bull. Soc. Hist. nat. Metz, (2), viii, 1898, p. 29 (*Arthrocnodax*); Ann. Soc. ent. Fr., lxi, 1901, p. 334 (*Diplosis*); Genera Insectorum, fasc. 152, 1913, p. 156.

Stefani, Ann. R. Staz. Speriment. Agrum. Fruttic., Acireale, iv, 1916-18, pp. 171-186 (R.A.E., A., vii, 1919, p. 413.)

Bagnall & Harrison, Ent. Rec., xxxvi, 1924, p. 37.

Barnes, Ann. Rept. Ent. Dept., 1925-6, S.E. Agric. Coll. Wye, Kent, 1926, p. 17.

Boselli, Boll. Lab. Zool. Portici, 1928, p. 249.

Larva, male and female described. Reared from larvae in big bud galls of *Eriophyes avellanae*, Nal. (1889), on *Corylus avellana* in Italy. Stefani noted *Arthrocnodax* spp. in a list of enemies of this mite. Bagnall & Harrison have found the yellow larvae of this species in Somerset and Shropshire, and Barnes has found it in Kent.

Arthrocnodax fraxinella, Meade = ? *Cecidomyia minuta*, Winn.

Meade, Ent. Mon. Mag., xxv, 1888, p. 77 (*Diplosis*).

Kieffer, Bull. Soc. Hist. nat. Metz, (2) ix, 1899, p. 14 (*Arthrocnodax*); Genera Insectorum, fasc. 152, 1913, p. 156.

Bagnall & Harrison, Trans. Ent. Soc. London 1917, 1918, p. 389.

Male and female described. The larvae were found as inquilines in flower galls, the cauliflower ash-gall, of *Eriophyes fraxinivorus*, Nal. (1909), on *Fraxinus excelsior* by Dr. Chapman in August 1887 in England. Kieffer (1900) states that the larvae are undoubtedly predacious on the mites.

Arthrocnodax gemmarum, Kieffer.

Kieffer, Feuilles Jeunes Natural. Paris, xxvi, 1895, p. 9; Bull. Soc. Hist. nat. Metz, (2) viii, 1898, p. 29; Genera Insectorum, fasc. 152, 1913, p. 156.

Male and female described. The larvae are predacious on *Eriophyes stenaspis*, Nal. (1891), in deformed buds and folds of leaves of beech in Lorraine.

Arthrocnodax incana, Rübs.

Rübsaamen, Verh. naturh. Ver. Preuss. Rheinl. Bonn, xlvii, 1890, pp. 20-21 (*Diplosis*); Wien. ent. Ztg., xiv, 1895, pp. 191-193 (*Arthrocnodax*).

Kieffer, Bull. Soc. Hist. nat. Metz, (2) viii, 1898, p. 29; Genera Insectorum, fasc. 152, 1913, p. 156.

Female only described. Reared from gall of *Dasyneura populeti*, Rübs., on *Populus tremula* in Germany. Probably a mite eater.

Arthrocnodax meridionalis, Felt.

Felt, Ent. News, xxiii, 1912, pp. 176-177; N.Y. St. Mus. Bull., no. 231-2, 1921, p. 85.

Kieffer, Genera Insectorum, fasc. 152, 1913, p. 156.

Larva, male and female described. Reared in May 1911 from open *Eriophyes* galls on the leaves of *Ruellia tuberosa*, Linn., doubtless preying upon the mites, by W. H. Patterson, St. Vincent, W.I.

Mr. Patterson, according to Felt (1912), obtained a similar, if not identical, species in May 1911 from *Eriophyes* galls on the leaves and bracts of *Lepidagnathis alopecuroidea*. He reared the same species in April 1911 from galls of *Eriophyes gossypii*, Banks (1904), on Sea Island cotton and also from mite galls on the leaves of a species of *Eupatorium*.

Arthrocnodax peregrina, Winn.

Winnertz, Linn. Ent. Stettin, viii, 1853, p. 252 (*Diplosis*).

Kieffer, Bull. Soc. Hist. nat. Metz, (2) viii, 1898, p. 30 (*Arthrocnodax*); Ann. Soc. ent. Fr., lxix, 1901, pp. 333-334 (*Diplosis*); Genera Insectorum, fasc. 152, p. 156 (*Arthrocnodax*).

Male described. Reared from larvae living in mite galls on *Prunus spinosa* and *Salix aurita* in Germany and Austria. Pupation takes place in the soil.

Arthrocnodax rhoina, Felt.

Felt, N.Y. St. Mus. Bull., no. 124, 1908, p. 404; *op. cit.*, no. 200, 1918, p. 159; *op. cit.*, no. 231-2, 1921, pp. 90-91.

Male described. Reared in August 1907 from curled sumac (*Rhus*) leaves at Albany, N.Y. Probably the larvae prey on a plant mite.

Arthrocnodax sambucifolia, Felt.

Felt, N.Y. St. Mus. Bull., no. 124, p. 404; *op. cit.*, no. 200, 1918, p. 188;
op. cit., no. 231-2, 1921, p. 91.

Larva and male described. Reared from rolled elder leaves (*Sambucus canadensis*) in September 1907 at Albany, N.Y. Felt states that it is probably predacious.

Arthrocnodax vitis, Rübs.

Rübsaamen, Wien. ent. Ztg., xiv, 1895, pp. 189-193; Z. wiss. Insektenbiol., ii, 1906, p. 234.

Kieffer, Bull. Soc. Hist. nat. Metz, (2) viii, 1895, p. 30; Genera Insectorum, fasc. 152, 1913, p. 156.

Larva, male and female described and figured. Recorded as living on *Eriophyes vitis*, Nal. (1890), on vine.

Lestodiplosis tarsonemi, Rübs.

Rübsaamen, Ent. NachrBl., Berlin, xxi, 1895, p. 184.

Kieffer, Bull. Soc. Hist. nat. Metz, (2) viii, 1898, p. 40; Ann. Soc. ent. Fr., lxix, 1901, p. 335; Genera Insectorum, fasc. 152, 1913, p. 198.

Male and female described together. The larvae were found in Germany in a swelling on the stem of *Arundo phragmites* which was inhabited by *Tarsonemus* sp.

Cecid. sp.

Warburton & Embleton (J. Linn. Soc. Zool., xxviii, 1902, p. 375) refer to the presence of what is claimed to be Cecidomyid larvae in "big buds" of black currant caused by *Eriophyes ribis* (Westw.) Nal. (1893). Massee (Bull. Ent. Res., xviii, 1928, p. 302) refers to this record.

5. Gall Midges whose Larvae may feed on Mites.

The larvae of certain gall midges have been known for a long time to live in the galls of mites. They may be living on the mites or as scavengers in the galls or simply asinquilines.

Kieffer (Ann. Soc. ent. Fr., lxix, 1901, pp. 333-335) refers to several old records. He states that the first observation of this nature was by Réamur, who found Cecid larvae in the corniculate galls of lime (*Tilia*). Bremi (Denkschr. allgem. schweiz. Ges. f. ges. Naturwiss. Neuenburg, xi, 1847, p. 30) indicated such larvae for the *Erineum* of *Poterium sanguisorbae* and in the straight margin leaf-roll of *Salix alba*. Kieffer (*loc. cit.*) quotes H. Loew as finding larvae in red galls the size of a grain of millet on the leaves of *Salix*. Winnertz, according to Kieffer (*loc. cit.*), states that larvae of midges are to be found in the galls of *Eriophyes thomasi*, Nal. (1889), on *Thymus serpyllum*, as Vallot and H. Loew had already recorded and as Perris (Ann. Soc. ent. Fr., x, 1871, p. 178) and Fr. Loew (Verh. zool.-bot. Ges. Wien, xxiii, 1874, p. 159) again recorded later. Perris (*loc. cit.*, p. 179) also gives four other examples of Cecid larvae living in Phytoptid galls on *Origanum*, *Lysimachia*, *Mentha rotundifolia* and *Trifolium subterraneum*. Von Frauenfeld (Verh. zool.-bot. Ges. Wien, xv, 1865, p. 898) recorded them in Phytoptid galls of *Euonymus*. Fr. Loew (*loc. cit.*) further recorded them in the galls of *Eriophyes galiobius*, Can. (1891), on *Galium verum*, of *Erineum alneum* on *Alnus glutinosa*, and of *Erineum betulinum* on *Betula*. He figured a larva which can be recognised, according to Kieffer (*loc. cit.*), as an *Arthrocnodax* species.

Rübsaamen (Wien. ent. Ztg., xiv, 1895, pp. 191-193) recorded finding larvae, belonging to the genus *Arthrocnodax*, predacious on *Eriophyes spiraeae*, Nal. (1895),

on *Spiraea crenifolia* in the Southern Urals. He also states that he found similar larvae on the leaves of *Artemisia camphorata* and *Viburnum lantana*.

The following midges have been reared from mite galls and may be predacious on the mites.

Microdiplosis zambezensis, Tav.

Tavares, Brotéria, vii, 1908, pp. 155-156.

Kieffer, Genera Insectorum, fasc. 152, 1913, p. 210.

Male and female described and figured as the generic type. Reared from various leaf-galls due to Phytotids in Mozambique, Africa.

Hyperdiplosis producta, Felt.

Felt, Ent. News, xxiii, 1912, p. 177; N.Y. St. Mus. Bull., no. 182, 1918, p. 182; *op. cit.*, no. 231-2, 1921, p. 125.

Kieffer, Genera Insectorum, fasc. 152, 1913, p. 211.

Male and female described. Reared by W. H. Patterson, St. Vincent, W.I., from presumably mite galls in the inflorescence of *Stachytarpheta jamaicensis*.

The following midges were described from caught specimens and nothing is known about their life-history. It seems likely, however, that their larvae are predacious on mites.

- (1) *Arthrocnodax acerina*, *cincta*, *fenestra*, *filicis*, *fraxini*, *incisa*, *obscura*, *rufa* and *sylvestris*, all of Felt.

References to their original descriptions and new descriptions are given by Felt, N.Y. St. Mus. Bull., no. 231-2, 1921, pp. 83-90. These are all American species and a specific key has been constructed (*op. cit.*, pp. 81-83).

- (2) *Arthrocnodax minuta*, Winn. (? = *fraxinella*, Meade).

Winnertz, Linn. Ent., Stettin, viii, 1853, p. 250 (*Diplosis*).

- (3) *Silvestrina minima*, Rübs.

Rübsaamen, Berlin ent. Zeits., xxxvi, 1891, pp. 50-52 (*Diplosis*).

The following species feeds on the excreta of mites.

Lestodiplosis (Coprodiptosis) entomophila, Perris.

Perris, Mém. Soc. Sc. Liège, x, 1855, p. 274 (*Cecidomyia*).

Kieffer, Bull. Soc. Hist. nat. Metz, (2) viii, 1898, p. 40 (*Coprodiptosis*); Ann. Soc. ent. Fr., lxi, 1901, pp. 336-337 (*Lestodiplosis*); Genera Insectorum, fasc. 152, 1913, p. 198 (*Coprodiptosis*).

Male and larva described. Reared from larvae found in France living on the excreta of mites attacking dried and pinned insects.

The following two species may have been feeding on mites.

Silvestrina ficorum, Barnes (Ann. Mag. Nat. Hist., (10) ix, 1932, p. 476) reared from fermenting dried figs in Algeria.

Silvestrina coprae, Felt (Philipp. J. Sci., xiv, 1919, pp. 291-292) originally reared from copra at Luzon, P.I. and more latterly from copra at Banting in the Malay Peninsula (Barnes, Ann. Mag. Nat. Hist., (10) ix, 1932, p. 479).

6. List of Plants on which Mites are attacked by Gall Midge Larvae.

A. FREE-LIVING MITES.

Plant and Mite	Midge	Country
<i>Althaea</i> (<i>T. telarius</i>)	<i>Feltiella venatoria</i> , Felt	U.S.A.
„ (red spider)	<i>Mycodiplosis</i> sp.	England
Apple, see under <i>Pyrus malus</i>		
<i>Arum</i> (<i>T. telarius</i>)	? <i>Therodiplosis persicae</i> , Kieff.	England
Bean, see under <i>Vicia faba</i>		
Bean, Garden (<i>T. bimaculatus</i>)	<i>Arthrocnodax constricta</i> , Felt	Porto Rico
<i>Chelidonium majus</i> (<i>Acarus</i>)	<i>Arthrocnodax acarisuga</i> , Vall.	France
Citrus spp. (<i>T. telarius</i> , <i>mytilaspidis</i> , <i>bimaculatus</i> , <i>sexmaculatus</i>)	<i>Arthrocnodax occidentalis</i> , Felt	U.S.A.
<i>Citrus medica</i> var. <i>limonum</i> (<i>T. mytilaspidis</i> , <i>sexmaculatus</i>)	<i>Mycodiplosis acarivora</i> , Felt	U.S.A.
<i>Convolvulus</i> (<i>T. telarius</i>)	<i>Therodiplosis persicae</i> , Kieff.	England
Corn (red spider)	<i>Mycodiplosis acarivora</i> , Felt	U.S.A.
Cotton, see under <i>Gossypium</i>		
Egg plant, see under <i>Solanum melongena</i>		
Elm, see under <i>Ulmus</i>		
<i>Gossypium</i> (<i>T. telarius</i>)	<i>Acaroletes tetranychorum</i> , Kieff.	S. Russia
„ (<i>T. telarius</i>)	<i>Mycodiplosis macgregori</i> , Felt	U.S.A.
„ (<i>T. telarius</i>)	<i>Arthrocnodax carolina</i> , Felt	U.S.A.
<i>Gymnocladus canadensis</i> (red spider)	<i>Mycodiplosis acarivora</i> , Felt	U.S.A.
Hollyhock, see under <i>Althaea</i>		
Hop, see under <i>Humulus lupulus</i>		
<i>Humulus lupulus</i> (<i>Tetranychus</i> sp.)	<i>Feltiella tetranychi</i> , Rübs.	Germany
<i>Hyacinthus</i> sp. (<i>Rhizoglyphus hyacinthi</i> , Banks)	<i>Lestodiplosis</i> sp.	U.S.A.
<i>Leonotis nepetaefolia</i> (red spider)	<i>Mycodiplosis insularis</i> , Felt	Porto Rico
<i>Melia azedarach</i> (<i>Tetranychus</i> sp.)	<i>Arthrocnodax rutherfordi</i> , Felt	Ceylon
Peach, see under <i>Prunus persicae</i>		
Pear, see under <i>Pyrus communis</i>		
Plum, see under <i>Prunus domestica</i>		
<i>Prunus domestica</i> (red mites)	<i>Feltiella americana</i> , Felt	U.S.A.
<i>Prunus persicae</i> (<i>T. telarius</i>)	<i>Therodiplosis persicae</i> , Kieff.	France, England

A. FREE-LIVING MITES—(continued).

Plant and Mite	Midge	Country
<i>Pyrus communis</i> (<i>Phyllocoptes schlechtendali</i> , Nal.)	<i>Arthrocnodax wissmanni</i> , Kieff.	Germany
<i>Pyrus mali</i> (<i>Phyllocoptes schlechtendali</i> , Nal.)	" "	Germany, England
" (mites)	<i>Arthrocnodax mali</i> , Kieff.	Germany
<i>Rosa</i> (red mites)	<i>Feltiella ithacae</i> , Felt	U.S.A.
<i>Saccharum officinarum</i> (<i>T. exsiccator</i>)	<i>Diplosis acarivora</i> , Zehnt.	Java
<i>Solanum lycopersicum</i> (<i>T. telarius</i>)	<i>Therodiplosis persicae</i> , Kieff.	England
<i>Solanum melongena</i> (<i>T. telarius</i>)	" "	England
Sugar-cane, see under <i>Saccharum officinarum</i>		
Tomato, see under <i>Solanum lycopersicum</i>		
<i>Ulmus</i> (<i>T. telarius</i>)	<i>Feltiella venatoria</i> , Felt	U.S.A.
" (mites)	<i>Cecid.</i> sp.	France
<i>Vicia faba</i> (<i>T. telarius</i>)	<i>Therodiplosis persicae</i> , Kieff.	England
Beehive debris (<i>Tyroglyphus</i>)	<i>Arthrocnodax apiphila</i> , Felt	U.S.A.
Flour (mites)	<i>Silvestrina farinicola</i> , Barnes	Italy
Seed of <i>Raphanus sativa</i> (<i>Aleurobius</i>)	<i>Lestodiplosis raphani</i> , Barnes	Denmark, England
Stuffed birds (mites)	<i>Lestodiplosis woeldickii</i> , Cont.	Italy

B. GALL-INHABITING MITES

Plant and Mite	Midge	Country
<i>Arundo phragmites</i> (<i>Tarsonemus</i>)	<i>Lestodiplosis tarsonemi</i> , Rubs	Germany
Ash, see under <i>Fraxinus excelsior</i>		
Beech, see under <i>Fagus</i>		
Black Currant, see under <i>Ribes nigrum</i>		
<i>Clematis cirrhosa</i> (<i>Epitrimerus heterogaster</i> , Nal., 1890)	<i>Arthrocnodax clematidis</i> , Marchal	Algeria
<i>Corylus avellana</i> (<i>Eriophyes avellanae</i> , Nal., 1889)	<i>Arthrocnodax coryligallarum</i> , T.-T.	Italy, England
Cotton, see under <i>Gossypium</i>		
<i>Eupatorium</i> sp. (mite leaf gall)	? <i>Arthrocnodax meridionalis</i> , Felt	St. Vincent, W.I.
<i>Fagus</i> (<i>Eriophyes stenaspis</i> , Nal., 1891)	<i>Arthrocnodax gemmarum</i> , Kieff.	Lorraine

B. GALL-INHABITING MITES—(continued).

Plant and Mite	Midge	Country
<i>Fraxinus excelsior</i> (<i>Eriophyes fraxinivorus</i> , Nal., 1909)	<i>Arthrocnodax fraxinella</i> , Meade	England
<i>Fraxinus velutina</i> (<i>Eriophyes fraxinivorus</i> , Nal., 1909)	<i>Arthrocnodax americana</i> , Felt	U.S.A.
<i>Gossypium</i> (leaf galls)	<i>Arthrocnodax abdominalis</i> , Felt	Peru
<i>Gossypium barbadense</i> (<i>Eriophyes gossypii</i> , Banks, 1904)	? <i>Arthrocnodax meridionalis</i> , Felt	St. Vincent, W.I.
Hazel, see <i>Corylus avellana</i>		
<i>Lepidagnathis alopecuroidea</i> (<i>Eriophyes</i> galls)	? <i>Arthrocnodax meridionalis</i> , Felt	St. Vincent, W.I.
<i>Populus tremula</i> (mites in gall of <i>D. populeti</i> , Rübs.)	<i>Arthrocnodax incana</i> , Rübs.	Germany
<i>Prunus spinosa</i> (mite galls)	<i>Arthrocnodax peregrina</i> , Winn	Austria, Germany
<i>Rhus</i> (probably mites in curled leaves)	<i>Arthrocnodax rhoina</i> , Felt	U.S.A.
<i>Ribes nigrum</i> (<i>Eriophyes ribis</i> (Westw.), Nal., 1893)	Cecid. sp.	England
<i>Ruellia tuberosa</i> (<i>Eriophyes</i>)	<i>Arthrocnodax meridionalis</i> , Felt	St. Vincent, W.I.
<i>Salix aurita</i> (mite galls)	<i>Arthrocnodax peregrina</i> , Winn.	Austria, Germany
<i>Sambucus canadensis</i> (probably mites in rolled leaves)	<i>Arthrocnodax sambucifolia</i> , Felt	U.S.A.
<i>Viburnum</i> (blister galls)	<i>Arthrocnodax apiphila</i> , Felt	U.S.A.
<i>Vitis</i> (<i>Eriophyes vitis</i> , Nal., 1890)	<i>Arthrocnodax vitis</i> , Rübs.	Germany

Notes on the Structure and Development of the Female Genital System in *Dasyneura* *leguminicola* Lint. (Cecidomyiidae-Diptera).

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With Plates 7 and 8 and 4 Text-figures.

CONTENTS.

	PAGE
I. INTRODUCTION	89
II. ADULT STRUCTURE	92
III. DEVELOPMENT	93
IV. CONCLUSIONS	97
1. The Ovipositor	97
2. The Efferent System	97
V. SUMMARY	102
VI. LITERATURE	102
EXPLANATION OF PLATES	104

I. INTRODUCTION.

THE study of the genital system in insects falls naturally into two sections for discussion, the external genitalia and the efferent system.

In the female, external genitalia of an appendicular nature associated with the eighth and ninth sternites are present in most orders, e.g. Thysanura (Verhoeff, 1902-3, 1910), Orthoptera (Walker, 1919; Nel, 1929, &c.), Hymenoptera (Kraepelin, 1873; Zander, 1899; Seurat, 1899; Haviland, 1921). The homologies of these appendages, their relations to each other and to the segment on which they are located, have an important bearing on the classification of the orders to which the insects belong.

In other orders the appendages may be reduced in number

and in size as in the Coleoptera (Verhoeff, 1893; Singh Pruthi, 1924; Metcalfe, 1932), or may be apparently completely absent as in most Diptera (Lowne, 1890-5). This condition is usually correlated with the elongation of the terminal abdominal segments and their modification to form a tubular retractile ovipositor carried within the body when at rest.

In the investigation of any order the questions arise as to whether true appendages are present and, if so, what are their homologies; or whether the ovipositor is derived from the modified terminal abdominal segments.

It is now generally accepted that the efferent system is derived from two sources—the original rudiments which are mesodermal in origin and give rise only to the paired ovaries and a portion of the paired ducts leading from them, and certain secondary structures of ectodermal origin (e.g. Singh Pruthi, George, Nel, Metcalfe). Whether these ectodermal structures are paired in origin as are the mesodermal strands, and the exact extent to which they supplement or replace the latter, are still matters of controversy.

The gonopore in the female is not constantly located posteriorly in a particular segment: in the male, on the contrary, it is always posterior to the ninth segment. In consequence the main efferent ducts in the different orders cannot be considered strictly homologous. This also renders the homologies of the male and female difficult to decide. Again, the relations of the accessory organs—glands, spermathecae, bursa copulatrix—to the main ducts are variable and their exact location has to be considered in each order before their homologies can be determined (Singh Pruthi, George, Nel, Metcalfe).

Owing to this variability it is not surprising that terminology is confusing, and that the same terms are used for structures having the same function but a different origin, in different orders.

For the sake of clearness some attempt has been made to stabilize the terms used in the following paper, in order that any particular duct may at once be referred to its point of origin. It will be found that the terms, with one exception, the vagina, are those which I have already made use of in discussing the

development of the female reproductive system in the Coleoptera and the Homoptera.

In the adult the main unpaired efferent duct has been termed the vagina. This opens posteriorly to the ninth sternite and receives dorsally the openings of a pair of accessory glands and a pair of spermathecae proper. The paired ducts leading from the ovaries to the vagina are called the oviducts, no distinction being made between their mesodermal and ectodermal portions.

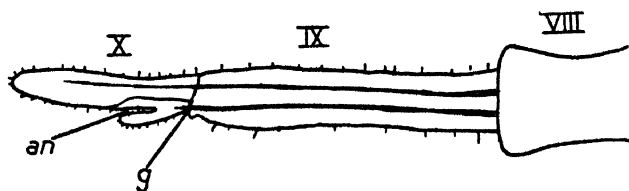
In the pupa the ectodermal invagination arising posteriorly to the eighth sternite is termed the uterine rudiment, its anterior branches the paired or lateral uteri. The ectodermal invagination originating posteriorly to the ninth segment is the spermathecal rudiment, its diverticula the rudiments of the spermatheca proper and the accessory glands. Where it has been found necessary to refer to the invagination posterior to the seventh segment, this is termed the rudiment of the common oviduct. The development of the reproductive system in different families of the Diptera has already been studied in detail (Lowne, 1890-5; Bruël, 1897; Kulagin, 1901; Awati, 1915-16; Christophers, 1922; Christophers and Barraud, 1926; Koch, 1929). In all the cases cited the female gonopore is located posteriorly to the eighth sternite, a curiously primitive position in an order so highly organized in other respects. There are some features in the structure of *Culex* as described by Christophers, however, which suggest that a duct may be present in some forms which arises posteriorly to the ninth segment. For this reason the Cecidomyidae were chosen for this study as being a family with close affinity to the Culicidae. Larvae, pupae, and adults of *Dasyneura leguminicola* Lint. being readily obtainable, this species was used as the starting-point for the investigation. The material was fixed in Carnoy's fluid, sectioned, and slides prepared in the usual manner.

It is hoped that an account of the male genital system will shortly be forthcoming, and that the conclusions reached herein will be confirmed by work on other Cecidomyids. The work was carried out at Rothamsted Experimental Station during the tenure of a Fellowship of the University of Wales.

II. ADULT STRUCTURE.

1. The Ovipositor (Text-fig. 1).

Ten abdominal segments are present in the adult female, the last four of which are modified to form a tubular retractile ovipositor. The first six segments are typical body segments of normal size and shape, the seventh is of the same length as



TEXT-FIG. 1.

Tip of extended ovipositor. $\times 18$.

LETTERING FOR PLATES 7 AND 8 AND TEXT-FIGS. 1-4.

ag, accessory gland; *an*, anus; *bv* (*sp*), anterior bend in vagina (spermathecal rudiment); *bd* (*sp.* + *ut*), posterior bend in vagina (transition from spermathecal to uterine rudiment); *cc*, chitinous cylinder; *f*, fat body; *g*, gonopore; *lut*, lateral uterus; *mt*, malpighian tube; *mu*, somatic muscle; *od*, oviduct; *ov*, ovary; *rect*, rectum; *rsp*, rudiment of spermatheca proper and accessory gland; *sp*, spermathecal rudiment; *spp*, spermatheca proper; *ut*, uterine rudiment; *v*, vagina; *v* (*sp*), vagina (spermathecal rudiment); *v* (*ut*), vagina (uterine rudiment); II-X, second to tenth abdominal segments.

the preceding segments, but is much narrower, being about as broad as it is long. The eighth and ninth segments with their intersegmental membranes are greatly elongated and are capable of being withdrawn partially or wholly within the body. Virgin females in the presence of males carry the ovipositor fully extended. After fertilization has taken place the terminal segments are withdrawn into the body and the abdomen then appears to consist of seven segments only. The gonopore is situated at the posterior border of the ninth sternite and is difficult to observe, except when the female is in the act of oviposition when it is seen to be a large and extensible aperture.

The tenth segment consists of a long and conspicuous tergite

and a small inconspicuous sternite between which the rectum opens. The tergite is much longer than the sternite (fig. 15, Pl. 8).

2. The Efferent System.

The ovaries lie one on either side of the abdominal cavity and extend from the posterior border of the third to the posterior border of the fifth segments. Each is composed of from six to eight ovarioles. The oviducts arise in the fourth segment, and unite ventrally with each other in the posterior region of the fifth segment. The vagina formed by their union is a long and narrow tube which, when the ovipositor is withdrawn into the body cavity, is looped forwards into the second abdominal segment. Here it enters, in company with the rectum, the double-walled cylinder formed by the retraction of the eighth and ninth segments. About half-way along its length the vagina gives rise dorsally to a single pair of tubular spermathecae and a single pair of accessory glands. When the ovipositor is withdrawn the spermathecae lie ventral to the vagina within the double-walled cylinder, while the accessory glands are free within the body cavity.

III. DEVELOPMENT.

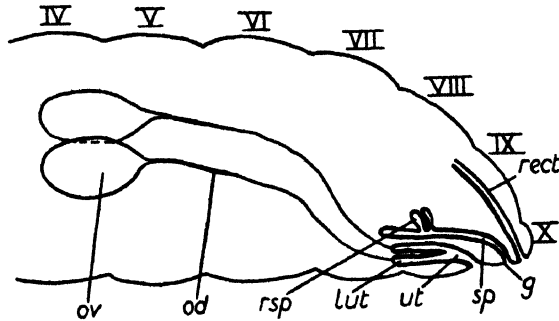
1. The Ovipositor.

Genitalia, in the sense of segmental appendages, being absent, the development of the ovipositor consists of the elongation of the eighth and ninth segments and their retraction into the body cavity. This does not begin until after pupation has taken place. In a young pupa the posterior segments are quite normal in shape and size. Very soon, however, the ectoderm in the ninth segment becomes much thicker (figs. 6-7, Pl. 7), and a groove is formed completely surrounding the anus and rudimentary gonopore. The groove deepens considerably, drawing with it first the whole of the ninth segment (Text-fig. 3) and later the eighth segment also. Eventually a double-walled chitinous cylinder, extending as far as the second abdominal segment in repose, is formed by the retraction of these two segments (Text-fig. 4).

2. The Efferent System.

In the larva the ovaries are present as small rounded bodies, situated in the dorso-lateral region of the sixth abdominal segment. Each ovary is continuous posteriorly with a solid strand of mesodermal tissue which reaches to the posterior border of the segment. This is the whole extent of the efferent system in the larva.

When pupation has taken place the ovaries are seen to have



TEXT-FIG. 2.

Diagrammatic longitudinal section through the abdomen of a young pupa.

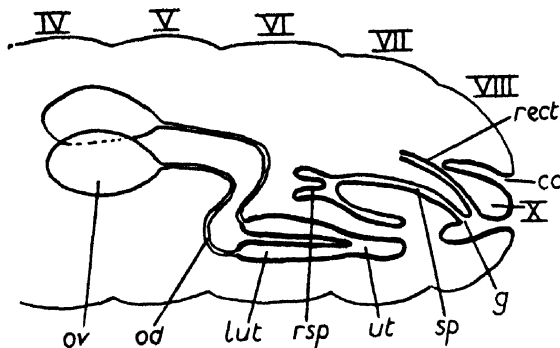
migrated anteriorly into the fourth segment. The oviducts are slender, solid cords of cells extending into the seventh segment (Text-fig. 2).

At the tip of the abdomen the thickening of the ectodermal layer already mentioned takes place. An invagination of this layer arises posteriorly to the ninth sternite and forms the rudiment of the spermatheca. This extends anteriorly into the seventh segment. About half-way along its length, in the eighth segment, it gives off dorsally a pair of blind outgrowths, the rudiments of the spermatheca proper and the accessory glands (figs. 1-7, Pl. 7; Text-fig. 2). Later these become redivided in a horizontal plane, the dorsal pair forming the spermathecae and the ventral pair the accessory glands (figs. 9-12, Pl. 8). About the same time a second invagination arises, posteriorly to the eighth sternite. This is the rudiment of the uterus and is a very short duct almost immediately

dividing to form two lateral arms, the paired or lateral uteri. These extend into the seventh segment where they join up with the blind ends of the paired oviducts (figs. 1-4, Pl. 7; Text-fig. 2).

As the pupa matures the ovaries increase in length and extend from the third to the fifth segments. The oviducts acquire a distinct lumen and the point of their union with the paired uteri can no longer be determined.

The telescoping of the posterior segments is also taking place,



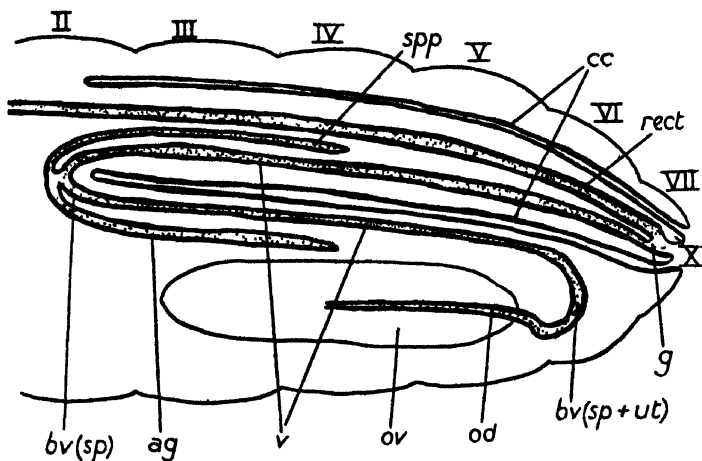
TEXT-FIG. 3.

Diagrammatic longitudinal section through the abdomen of an older pupa.

and as this proceeds the rudiments of the spermatheca and uterus are carried forwards as shown in Text-fig. 3. The uterus loses its external opening posterior to the eighth sternite and is moved anteriorly as a whole, the relative positions of its parts being unaltered. The point of division of the paired uteri thus becomes displaced into the sixth segment, while the closed-over posterior end is situated in the seventh segment. The spermathecal rudiment, on the other hand, is thrown forwards in a loop, so that the point of origin of the spermatheca proper and accessory glands is now carried to the anterior border of the seventh segment, while the anterior blind end of the main duct remains in the middle of the seventh segment immediately dorsal to the blind end of the uterine rudiment (see Text-fig. 3). These two blind ends now become opposed to one another, their intervening walls break down, and a through passage is

established from the uterine rudiment to the spermathecal rudiment: from the ovaries to the gonopore (figs. 13 and 14, Pl. 8). The composite duct formed by the joining up of these rudiments is the vagina.

Growth in the vagina (spermathecal rudiment) now keeps pace with the increasing elongation of the eighth and ninth



TEXT-FIG. 4.

Diagrammatic longitudinal section through the abdomen of a fully developed pupa. (N.B.—The proportion of the diameter of the chitinous cylinder to the body cavity has been increased for the sake of clearness. Also, the ovary is shown ventral to the chitinous cylinder instead of dorso-lateral.)

segments, so that eventually the point of origin of the spermathecae and accessory glands is carried anteriorly into the second segment. The posterior bend (spermathecal + uterine rudiments) in the vagina now lies at the anterior border of the sixth segment (Text-fig. 4).

The development of the reproductive system is now complete, and the transit from the pupa into the imago is marked by the shrinkage of the walls of ectodermal origin and their deposition of a chitinous lining.

The vagina is thus formed by the union of two separate ectodermal ducts, the one originating posterior to the ninth, the other to the eighth sternites. The latter loses its external

opening, and the functional gonopore is the aperture of the original spermathecal rudiment located posterior to the ninth sternite.

IV. CONCLUSIONS.

1. The Ovipositor.

True genital appendages are absent in *Dasyneura leguminicola*. The posterior abdominal segments are modified in relation to oviposition, as is the case in the female Coleopteron. Kieffer (1900) distinguishes three types of ovipositor in the family Cecidomyiidae, each more or less related to the mode of oviposition. These are (a) the oviducte à pochette, the type present in *D. leguminicola*. The ovipositor is usually elongated and capable of retraction. It ends in an appendage which bears the gonopore ventrally, and a tiny median appendage ventral to the gonopore. It is incapable of perforating plant tissues. (b) The oviducte aciculaire is also retractile, but is needle-shaped. Its extremity is pointed and the gonopore is situated a little anteriorly to the tip. A tiny ventral appendage is present in some forms and the ovipositor is said to be capable of the perforation of plant tissues. (c) The oviducte à lamelles may be retractile, but most often is not. The gonopore is bordered dorsally by a pair of plates, and ventrally one or two plates may also be present. The dorsal plates show diversity of form and may be simple or two or three jointed, fused basally or distinct from one another. Kieffer advances the opinion that the first two types are derived by fusion from the third. From his description the small plates ventral to the gonopore suggest true genital appendages. The small plate in *D. leguminicola*, however, is dorsal to the gonopore as has already been shown in *Mayetiola avenae* March. by Ricchello (1929), who regards it as the sternite of the tenth segment. There seems to be some foundation for this statement of Ricchello's, since the anus opens between the two plates.

2. The Efferent System.

The original genital strands, that is to say, the ovaries and mesodermal oviducts, are the only parts of the efferent system

derived from the mesoderm. The oviducts in the early pupal stages attain their maximum development and extend into the seventh abdominal segment. Later they are partially replaced by ectodermal outgrowths from the uterine rudiment, so that the oviducts in the adult are partly mesodermal, partly ectodermal in origin. This has already been shown to occur in the Coleoptera (Singh Pruthi, Metcalfe) and Hemiptera (Metcalf, 1932), though in the latter case the ectodermal portions are derived from the common oviduct and not from the uterus.

The rest of the efferent system is ectodermal in origin. This has already been shown in the Diptera by Lowne, Bruël, Christophers, Christophers and Barraud, and by Koch. It has also been demonstrated in other orders by many workers. A notable exception is George, who finds that the anterior region of the common oviduct in *Agrion* is derived from the fused mesodermal oviducts: the terminal region is ectodermal.

The main ducts of the efferent system are unpaired in origin. This also is a general conclusion for the Diptera. In the point of origin of the main efferent ducts, however, *D. leguminicola* differs markedly from other Diptera that have been described.

The gonopore in *D. leguminicola* is located posteriorly to the ninth sternite. It has a similar situation in *Mayetiola avenae* March. (Ricchello). According to other workers who have investigated the efferent system in the Diptera, e.g. Lowne and Bruël (*Calliphora erythrocephala*), Kulagin (*Culex* and *Anopheles*), Christophers (*Culicidae*), Christophers and Barraud (*Phlebotomus*), Awati (*Calypterae*), Sturtevant (*Acalypterae*), 1925, and Koch (*Psychoda alternata* Say), the female gonopore is situated posteriorly to the eighth sternite. The *Cecidomyiidae* therefore appear to form a distinct group.

It is known, however, that in the females of the Hexapoda generally, the gonopore is not found located constantly posteriorly to a particular segment as in the male, but may lie posteriorly to the seventh (*Ephemeroptera*—Morgan, 1913; *Orthoptera*—Wheeler, 1900; *Orthoptera* (some)—and *Dermaptera* (some)), to the eighth (*Orthoptera*—Walker, Nel; Hemi-

ptera—Christophers and Cragg, 1921-2; Singh Pruthi, 1925; George, Metcalfe), or to the ninth segment (*Bombyx mori*—Verson and Bisson, 1896; Hymenoptera—Kraepelin, Zander, Kulagin, 1897-8; Haviland; Coleoptera—Singh Pruthi, Metcalfe). The gonopore in the different groups cannot therefore be considered strictly homologous, being sometimes the original aperture of the common oviduct, sometimes of the uterus, and sometimes of the spermatheca. The rudiments of all three ducts may be present and their apertures open at some stage in development. Thus in the Hemipteron *Philaenus spumarius* the common oviduct is present in the early stages. Later the uterus is formed, the common oviduct losing its aperture and opening into the uterus. The latter retains its function as the main efferent duct, and its aperture, posteriorly to the eighth sternite, is the gonopore. An ectodermal duct arising posteriorly to the ninth sternite—the ‘spermathecal invagination’—forms the main accessory gland and, retaining its aperture, does not come into communication with the uterus (Metcalfe).

In the Coleoptera, also, all three rudiments are present. The rudiment of the common oviduct, however, has no connexion with the efferent system in the adult, but exists merely in the form of a supporting chitinous rod. The uterus opens to the exterior in the early pupal stages, but later loses this opening and joins up with the spermathecal rudiment. The latter, besides giving rise to the functional spermatheca and accessory glands, forms the main efferent duct; and its aperture, posterior to the ninth segment, is the gonopore (Metcalfe).

In the Macrolepidoptera the ducts arise from the eighth and ninth segments, and although communication is established between them, two separate apertures are retained, the one posterior to the eighth segment being the aperture of the bursa copulatrix and the one posterior to the ninth being that of the ‘azygos oviduct’ (Jackson, 1888-94).

In the Diptera-Calyptræ, as typified by *Calliphora erythrocephala*, only the uterine rudiment, originating posteriorly to the eighth segment, is present, and gives rise to the main efferent duct and its appendages (Lowne, Bruël).

Similarly the main efferent duct in *Psychoda alternata*

arises posteriorly to the eighth segment; while the accessory gland originates in the same region of the ectoderm, and retains its external opening immediately behind the gonopore. No spermathecae are present (Koch).

In the mosquito *Culex* the uterus ('common oviduct') and spermatheca proper originate posteriorly to the eighth segment and retain their separate openings. An invagination named the caecus, which receives the opening of the accessory gland, arises posteriorly to the ninth segment; this also retains its aperture and does not come into communication with the uterus (Christophers).

The evolutionary chain in the Diptera suggested above is completed by *D. leguminicola*. As has been shown, the main efferent duct in this insect is derived from two separate and distinct rudiments, the one originating posteriorly to the eighth segment and the other to the ninth. The former loses its external aperture, and communication is established with the posterior duct which functions as the main efferent channel, its aperture being the gonopore.

With the exception of the fact that the rudiment of the common oviduct is not present in *D. leguminicola*, its development most nearly approximates to that in the Coleoptera. The table of comparisons on p. 101 clarifies the situation in the Diptera and Coleoptera.

Recently it has been suggested that the line of evolution in the female efferent system in insects lies along the posterior movement of the gonopore (Singh Pruthi, George, Nel, Metcalfe), and this conclusion is further borne out by the evidence from the Diptera given above. An interesting question presents itself here, namely, whether the Cecidomyiidae are more advanced in the development of the female reproductive system than are the Calypterae. It is possible that the location of the gonopore posterior to the eighth sternite in the latter group is primitive; but it also may have come about by the degeneration of the spermathecal rudiment, although this process has not been observed hitherto. A further explanation is possible: the number of abdominal segments present in the adult Calypterae is nine. In the male the missing segment is the pregenital

Structure.	Diptera.			Coleoptera (Metcalf).
	<i>Calliphora</i> (Lowne, Bruël).	<i>Culex</i> (Christophers).	<i>Dasyneura</i> (Metcalf).	
Rudiment of common oviduct	—	—	—	Chitinous rod.
Aperture posterior to 7th segment	—	—	—	Closed over.
Rudiment of uterus	Main efferent duct	Main efferent duct	Secondary efferent duct	Secondary efferent duct.
Aperture posterior to 8th segment	Open = gonopore	Open = gonopore	Closed	Closed.
Rudiment of spermatheca	—	'Caecus'	Main efferent duct	Main efferent duct.
Opening posterior to 9th segment	—	Open	Open = gonopore	Open = gonopore.

segment, namely, the eighth (Lowne, Awati). Should the missing segment in the females also prove to be the pregenital, then the gonopore becomes located posteriorly to the ninth segment, and the evolutionary chain in the Diptera suggested above is reversed, with *Psychoda* and *Culex* as the primitive forms, *Dasyneura* as the intermediate phase, and the Calypterae as the most advanced forms.

With regard to the appendages of the efferent system, viz. the accessory glands and the spermathecae: in *D. leguminicola* these are unpaired and ectodermal in origin, arising from the spermathecal rudiment as in the Coleoptera. According to Nel, the original location of the spermatheca is on the eighth segment. This is borne out to some extent by the work of Christophers, George, and Jackson. Nel regards the position of the spermatheca in the Coleoptera as described by Singh Pruthi as 'exceptional and specialized' (loc. cit., p. 71). This condition is, however, present in *D. leguminicola*. Furthermore, the spermatheca in *Culex* as described by Christophers

arises in exactly the same position as the accessory glands in *Psychoda alternata* as described by Koch. In the latter insect spermathecae are absent. If it be supposed that the spermatheca in *Culex* is really the accessory gland while the caecus is the functional spermatheca, then the comparison between the Cecidomyidae and the Culicidae is carried a step farther.

There seems to be no reason why the spermathecal function, as well as the gonopore, should not undergo a posterior migration.

Jackson's view that the accessory glands are paired in origin has been recently revived to some extent by Christophers and Barraud, George and Nel. In all cases the glands described by these authors arise directly from the ectoderm. In the Coleoptera and in *D. leguminicola* the glands arise as paired outgrowths from an originally unpaired structure and must therefore be considered as fundamentally of unpaired nature.

It is unfortunately impossible at the present time to compare the structure of the male with that of the female, but it is hoped that this will appear in a later paper.

V. SUMMARY.

1. Genitalia of an appendicular nature are absent in *D. eguminicola*, the terminal abdominal segments being modified to form a tubular retractile ovipositor.

2. Apart from the ovaries and a portion of the paired oviducts, the efferent system is unpaired and ectodermal in origin.

3. The gonopore is posterior to the ninth sternite, and is derived from the primitive spermathecal invagination as in the Coleoptera.

4. The uterine rudiment is present during the early stages of development, but later becomes closed over, discharging its contents into the duct derived from the spermathecal rudiment.

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EXPLANATION OF PLATES 7 AND 8.

LETTERING FOR PLATES 7 AND 8 AND TEXT-FIGS. 1-4.

ag, accessory gland; *an*, anus; *bv* (*sp*), anterior bend in vagina (spermathecal rudiment); *bd* (*sp.* + *ut*), posterior bend in vagina (transition from spermathecal to uterine rudiment); *cc*, chitinous cylinder; *f*, fat body; *g*, gonopore; *lut*, lateral uterus; *mt*, malpighian tube; *mu*, somatic muscle; *od*, oviduct; *ov*, ovary; *rect*, rectum; *rsp*, rudiment of spermatheca proper and accessory gland; *sp*, spermathecal rudiment; *spp*, spermatheca proper; *ut*, uterine rudiment; *v*, vagina; *v* (*sp*), vagina (spermathecal rudiment); *v* (*ut*), vagina (uterine rudiment); II-X, second to tenth abdominal segments.

PLATE 7.

Figs. 1-7.—Transverse sections through the posterior abdominal segments of a young pupa from anterior to posterior.

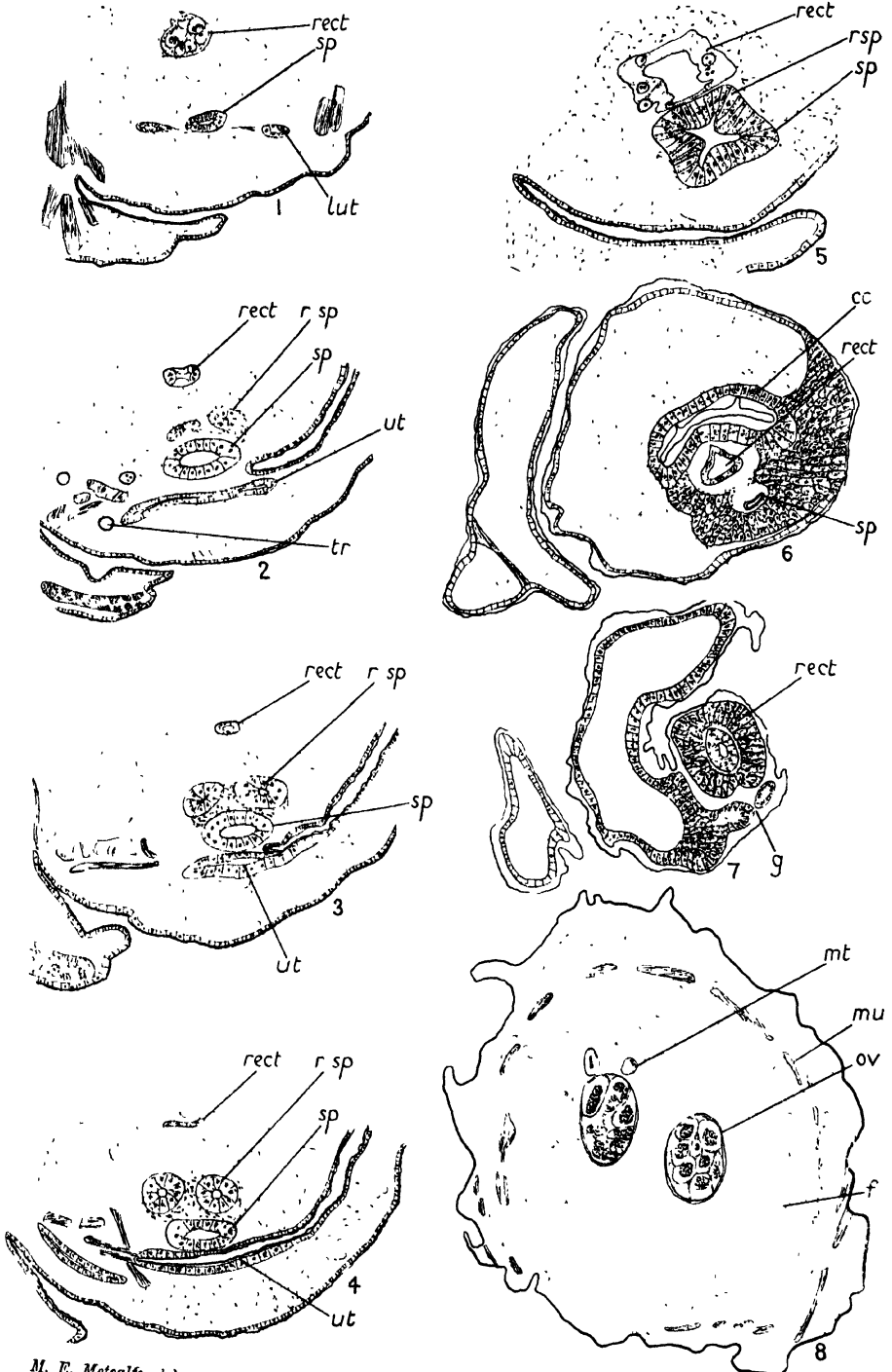
Fig. 1.—The spermathecal rudiments and paired uteri. $\times 173$.

Fig. 2.—The spermathecal and uterine rudiments. $\times 173$.

Fig. 3.—Origin of uterine rudiment. $\times 187$.

Fig. 4.—Section a little posterior to fig. 3. $\times 180$.

Fig. 5.—Origin of the common rudiments of the spermatheca proper and accessory glands. $\times 217$.



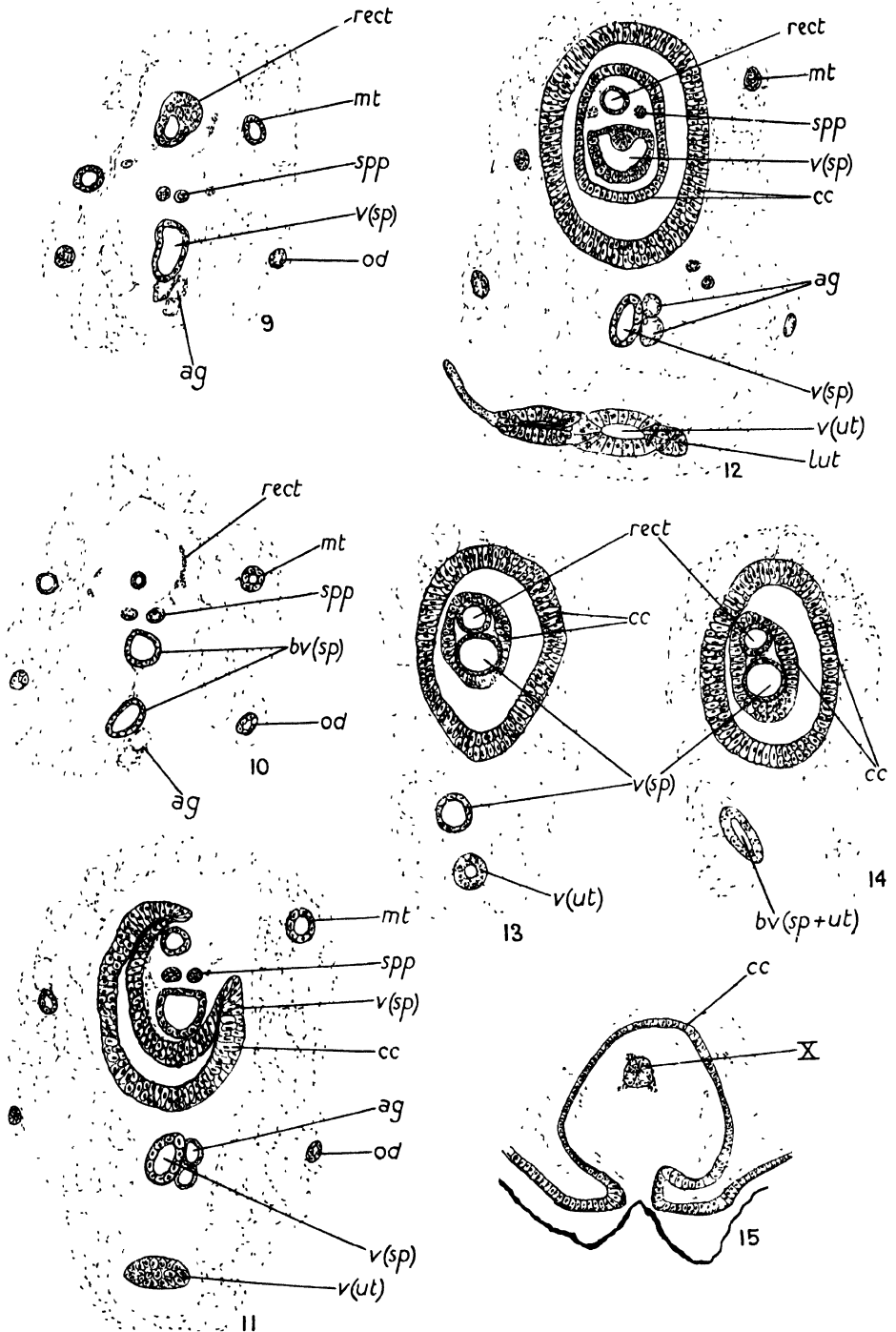


Fig. 6.—The telescoping of the posterior segments. $\times 140$.

Fig. 7.—The gonopore. $\times 167$.

Fig. 8.—Transverse section through the fourth abdominal segment of an older pupa showing ovaries. $\times 103$.

PLATE 8.

Figs. 9-15.—Transverse sections through the abdomen of an older pupa from anterior to posterior.

Fig. 9.—Showing anterior bend in the vagina. $\times 217$.

Fig. 10.—Separation of two limbs of vagina. $\times 233$.

Fig. 11.—The telescoped posterior segments and blind end of uterus. $\times 253$.

Fig. 12.—Division of the uterus. $\times 267$.

Figs. 13 and 14.—The posterior bend and union of the uterus and spermathecal rudiments. $\times 233$.

Fig. 15.—The tenth segment posterior to the anus. $\times 233$.

[FROM THE ANNALS OF APPLIED BIOLOGY, VOL. XX, No. 1,
pp. 100-116, FEBRUARY, 1933.]
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THE PHYSIOLOGY OF VIRUS DISEASES IN PLANTS

IV. THE NATURE OF THE VIRUS AGENT OF AUCUBA OR YELLOW MOSAIC OF TOMATO

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(With 1 Text-figure.)

DURING the past few years, as the symptomatology of plant virus diseases has been increasingly clarified, more attention has been directed to the study of the nature of the virus. Recently, it has been shown by Barnard that the probable agent of one of the animal diseases hitherto considered as a virus disease can be seen under suitable conditions. Elford (4) has, at the same time, shown by improved filtration methods that the size of the agent would correspond with Barnard's observations. Even yet, however, most of the virus disease agents appear to be much smaller than that investigated by Barnard and Elford (1).

One of the main difficulties of technique which so far has confronted the workers on the nature of the agent has been the impossibility of culturing the virus *in vitro*. Kendall has recently developed a technique by which it is possible to induce the formation of a filter-passing stage in bacteria, and this may prove to be of value in virus work. At present, however, the only reported case of multiplication of a plant virus in a dead culture medium—that of tobacco mosaic—has not been confirmed (7).

That the virus is an organism is becoming more and more widely believed, at least as a working hypothesis, and the demonstration of the presence of particles in serum from a diseased animal rather supports this belief. How far, however, the particulate nature of the virus may be due not to the virus itself but to the aggregation round it of cell constituents, is a point not yet settled. It has been shown for many virus diseases that one characteristic symptom is the formation of precipitation products in the cytoplasm. It is easily shown, also, that the virus is intimately associated with the normal cell contents, since it is readily precipitated with the cell proteins. At the same time, the observation that some plant

viruses apparently increase in virulence if the macerated juice be kept for some days is not necessarily evidence of disintegration of masses of virus as Olitsky (7) has suggested. It may be due to the breakdown of cellular material and the release of particles in that way. Later in this paper it is shown that there is little evidence for supposing that the virus of aucuba or yellow mosaic of tomato is normally aggregated into masses either mechanically or by adsorption round a large protein body.

In work with animal viruses and, until recently, with plant viruses, the study of the particulate nature of the agent and the nature of the particle, if such existed, was complicated by the fact that the only method of assessing the presence of the agent was by inoculation of small amounts into healthy host animals or plants. This method does not readily allow of work with large volumes of liquid, and sampling at high dilutions is rendered more than usually difficult. As a consequence, little information is available as to the number of virus bodies required to induce infection, except that it appears to be small, or the number of virus bodies present in an infected cell, except that it appears to be very large.

A recent paper of Holmes (6) has directed attention to the fact that one type of experiment would furnish useful data on this problem. This could be carried out with a "standard" virus on a plant, and the conditions are such that unusually large numbers of plants need not be used. Holmes showed that when tobacco mosaic juice was rubbed on to the leaves of *N. glutinosa* and numerous other of the Solanaceae, lesions appeared on the rubbed leaves. The earlier and now obsolete technique which had insisted on the perforation of the lamina of the infected leaf had, by the extensive damage done, largely prevented the recognition of the local lesions.

As it is possible to bring about the infection of the plant merely by rubbing the leaves sufficiently roughly to ensure that a number of the hairs are broken without at the same time damaging the mesophyll tissues the local effect of inoculation may readily be examined. It has been found, for instance, with aucuba mosaic in tobacco, that the first symptoms which develop are local lesions on the rubbed leaves, and these precede the more usual symptom of chlorosis of the developing leaves.

The writer has shown in an earlier paper (3) that the aucuba or yellow mosaic of tomato has a similar effect on *N. glutinosa* and also on tobacco. The interesting point is that under the conditions in our experimental glasshouses the disease does not, in *N. glutinosa*, at any time become systemic, but that the symptoms and indeed the agent are localised on the rubbed leaves. At the same time the writer has shown

that the appearance of symptoms on the *N. glutinosa* depends on the damaging of leaf tissue, and that while it is not necessary to perforate the lamina as had regularly been done heretofore, it was necessary, to ensure infection, to break the hairs on either side of the leaves. Holmes has pointed out that the number of necrotic lesions which occurred on the leaves was some index of the dilution of the sample of infectious juice, that is of the amount of virus present in the inoculum. He apparently inoculated the leaves by rubbing with a piece of cotton-wool soaked in the juice, and the method does not allow of very careful analysis of the data. It was evident, however, that if a suitable method were devised one had here a technique for demonstrating that the virus agent was particulate in nature and also of assessing the probable numbers of the particles present in any given inoculum.

If it could be shown that the number of necrotic areas bore a definite and constant relation to the amount of dilution then the supposition would be that the agent was particulate. If it could, further, be shown that the number of necrotic areas could not be increased in any given dilution by any treatment calculated to break down aggregates of particles or to free particles of the agent from adsorbing materials, then the presumption would be that the virus particles were separate entities which could exist alone. It would be shown, therefore, not only that one particle was sufficient to induce the formation of the given symptom but also that the number of such particles could be calculated to a fair degree of accuracy.

By the use of such a plant as *N. glutinosa*—tobacco was used to check the observations—it was possible to carry out accurate experiments on a sufficiently large scale—since each leaf acted as a separate organism, and the total number of plants used was comparatively small. It has been pointed out in a previous paper in this series that the symptoms can and do appear on leaves of *N. glutinosa* which have actually been detached from the plant(3), and that the agent does not move about the plant. The top of a plant infected below is quite normal and, in fact, the virus does not travel across the lamina of the rubbed leaf on to the uninoculated portions.

METHODS AND MATERIALS.

The infectious juice was prepared by macerating in a mortar a number of leaves of tomato or of tobacco from plants showing good, typical symptoms of aucuba mosaic. To the crushed pulp was added distilled water in the proportion of 2 c.c. of water to 1 gm. of pulp. This

was thoroughly mixed with the tissue and the whole left for 24 hours on the laboratory bench. Thereafter, the pulp was put into muslin and as much as possible of the liquid expressed. This liquid was then passed through a fluted filter paper impregnated with fuller's earth when the filtrate was clear and brown coloured. This liquid was considered as the source of material, and dilutions were made from this as stock. Some of this material was freshly prepared for each experiment.

In the earlier experiments, which were of a preliminary nature, the stock material was diluted by the addition of 10 to 90 c.c. of water giving 1/10 dilution; of that 10 c.c. were added to 90 c.c. of water giving 1/100 dilution and so on. After each dilution the liquid was mixed as thoroughly as possible by prolonged shaking.

The diluted material was put on to the experimental plants. Plants of *N. glutinosa* with some five to ten leaves were taken, and on to each leaf was rubbed 0.1 c.c. of inoculum. This inoculum was carefully spread with the top of the index finger over the whole surface of the leaf, an attempt being made to break the hairs on the adaxial side without, so far as possible, damaging the tissues of the mesophyll. It has already been shown that rupture of the living cells must be made before infection can take place and the necrotic lesion, the only symptom, be formed (3).

EXPERIMENTS ON SERIAL DILUTION.

In the first experiment, the number of leaves used was five in each group and each was rubbed with 0.1 c.c. of inoculum as described. The top of each plant was removed, following the practice of Holmes, and an examination of the plants was made a week after treatment. The results are indicated in Table I.

Table I.

Number of spots on ten treated leaves of N. glutinosa.

Dilution	1/100	1/1000	1/10,000
No. of spots (total)	146	14	2

In another experiment the results were similar. In this instance, the number of leaves used was ten on each plant, and total numbers obtained for each dilution are shown in Table II.

Table II.

Experiment B. Number of spots on ten treated leaves of N. glutinosa and different dilution.

Dilution	1×10^{-1}	1×10^{-2}	1×10^{-3}	1×10^{-4}	1×10^{-5}
No. of spots (total)	449	562	68	8	1

In this experiment at dilutions 1×10^{-1} and 1×10^{-2} the number of broken hairs seems to have been a factor of much importance, as evidenced by the abnormal results obtained, but in the rest of the series, as in the previous experiment, the results are very significant.

This result has been confirmed on many occasions, and there seems to be no doubt that the number of spots obtained bears a direct relation to the dilution under the conditions of this experiment. The relationship breaks down at high concentrations where apparently there are not enough broken hairs to admit of the entry of the agents present and where actually more agents enter at a broken cell than is necessary as a minimal infection dose.

One point has to be borne in mind and that is that the hairs are not so easily broken on the slightly immature leaves, indeed the ease with which hairs are broken tends to vary from leaf to leaf with various environmental or physiological conditions. The distribution of the spots on the leaves in one dilution is shown below:

Leaf from top	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th
No. of spots	5	21	24	28	49	22	34	45	50	28	28

It was generally found that the younger leaves at the top of the plant were consistently less well-spotted than those lower down, though in the later experiments, with more experience, the distribution of spots became more regular and the method much more accurate. The reason for the fewness of the spots on the upper leaves seems to be the less brittle nature of the hairs on these leaves. It has been clearly demonstrated that rupture of the cells is necessary for infection, and the rupture takes place usually at the hair base. If the hair base be fairly tough and can resist the not very great pressure of the finger, clearly the chance of infection is reduced. Another point which is of interest is that the necrotic areas on the upper leaves are consistently smaller than are those on the lower. It has been suggested before that the amount of multiplication which takes place in these areas is small, and that the effect of the agent is to kill a few cells round the point of inoculation (cf. (2)). When the leaves are mature and the mesophyll cells of the full size are separated by fairly large intercellular spaces, the area affected by the collapse of a given number is much larger than it would be if the same number of cells were more compact and not so well developed. Observations of this kind must necessarily be borne in mind in any consideration of the experiments.

Yet another point which is of great importance in these experiments is that the amount of pressure which has to be applied is restricted

within quite narrow limits. The hairs of the adaxial side must be broken fairly evenly over the surface to allow of the entry of all the virus particles into ruptured cells. At the same time it has been shown that excessive rupture of the mesophyll cells, which are the cells responsible for the exhibition of symptoms, will prevent the development of any symptoms. The writer has often found that light rubbing on one half of a leaf induced symptoms on that side whilst heavy rubbing on the other half induced the appearance of few or no symptoms.

So far as our experience here is concerned, the difference between leaves is great. On some plants rubbing of a given inoculum induces many necrotic spots per leaf, while on others the same inoculum similarly treated induces but few. Environmental conditions also play an important part in determining whether the hairs on the leaf will be easily broken off or not.

MORE DETAILED EXPERIMENTS ON DILUTION.

The results of the experiments involving dilutions of 1/10, 1/1000, 1/10,000, etc., were so satisfactory that it seemed desirable to decrease the interval between the dilutions. That is to say, the dilutions were made so that each in the series was twice as dilute as the one preceding it. Such a series is common in bacteriological technique and affords a satisfactory method of counting the bacterial numbers. The same general method was employed as before. Plants of *N. glutinosa* were selected which were just on the point of flowering. Normally, under our conditions, plants at this stage have ten or twelve well-developed leaves and have perhaps sixteen leaves in all. The lower seven or so leaves were removed as was also the whole top of the plant, together with the uppermost three leaves. As a consequence there remained five or six well-formed, uniform leaves mature and normal in type which afforded, as evidenced by a large body of data, the best material for the development of necrotic lesions. In these leaves there are more consistent numbers of spots than in leaves chosen on the whole plant, where, as we have seen, the upper and lowermost leaves have fewer spots than have those in the middle portion. Even in the leaves of the middle portion of the plant, however, it is not possible to ensure that the rubbing be sufficiently hard to break a large enough number of hairs to ensure that broken hairs be not a limiting factor and be not so rough as to cause damage to the soft mesophyll tissues which are very easily crushed even in the toughest leaves. It does not seem to be possible to overcome this difficulty

completely, and attempts at removing the hairs by "shaving" with a sharp razor have been even less successful than the method outlined.

In these experiments, as has been pointed out, the dilution was in each case twice that of the previous and, consequently, in the light of the factors which have been outlined above, very close agreement was hardly expected. Actually, the results obtained were very good and approximated to the theoretical.

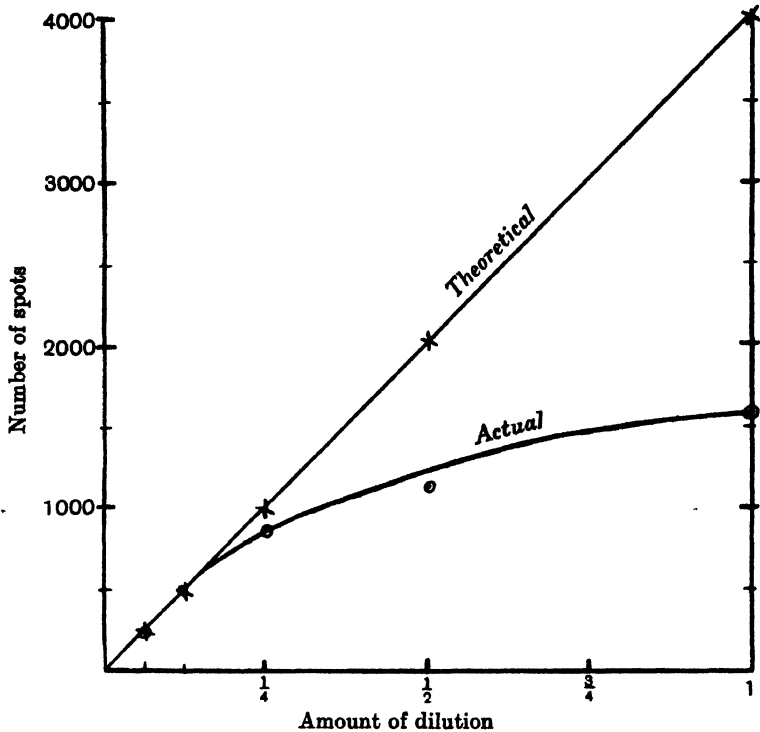


Fig. 1. Graph showing the relationship between the theoretical and observed number of spots with certain dilutions.

In most experiments it was clear that, at the higher concentrations of juice, the number of broken hairs on the leaf surface became a limiting factor. This was well borne out in an experiment in which the undiluted juice was used, the second inoculation was that juice diluted $1/2$, the third $1/4$ and so on. The figures obtained were 1610, 1090, 882, 540 and 245 as totals of the numbers of spots on ten leaves rubbed with juice, undiluted, diluted $1/2$, $1/4$, $1/8$, $1/16$ respectively. If one assumes that the lowest figure was correct at 250 the series would have been, 250, 500, 1000, 2000 and 4000 for the required dilutions. It is clear that at the

higher concentrations, some factor has operated, which was not the amount of virus present. The higher the concentration, *i.e.* the greater the amount of virus in the inoculum, the greater is the discrepancy between the observed and the theoretical results. It would appear, therefore, that the factor which is mainly concerned with the discrepancy lies in the tissues rather than in the inoculum. It seems reasonable to assume that the number of hairs which were broken was insufficient to make available a large enough number of points of inoculation to render effective all the virus. Results of this experiment are set out in Fig. 1, where it will be seen that the discrepancy between the theoretical and the observed results is much greater as the numbers increase in size.

The preliminary experiment had shown that dilutions of about 1/50 furnished useful material for this work and did not induce the formation of too large numbers of spots. Here, again, there was great individual variation, and it was not possible accurately to foretell the strength of a virus inoculum from the intensity of symptoms on the plant from which it was taken. Actually, the less well-grown plants in the glasshouse during November had rather higher virus content than those grown in the spring and early summer.

The results of some of the experiments are given in Table III.

Table III.

Total numbers of necrotic spots on ten leaves of N. glutinosa.

Inoculum 0.1 c.c. Aucuba mosaic juice at given dilution.

Date								
Feb. 15th:								
Dilutions	1/250	1/500	1/1000	1/2000	1/4000			
No. of spots	365	207	105	44	36			
Apr. 22nd:								
Dilutions	1/250	1/500	1/1000	1/2000	1/4000			
No. of spots	296	113	49	26	—			
Aug. 12th:								
Dilutions	1/50	1/100	1/200	1/400	1/800	1/1600	1/3200	1/6400
No. of spots	530	300	230	90	40	50	11	3

From these data, which are only a few of the many experiments carried out, there is strong presumptive evidence, all the above-noted considerations being taken into account, that there is a direct and simple relationship between the dilution and the number of spots when equal amounts are used on each leaf. The inference drawn is that the virus agent is apparently particulate in nature, and that each particle, or group of particles, is able to induce the appearance of a necrotic spot on the leaf of *N. glutinosa* if entry into a cell be effected.

THE DISINTEGRATION OF AGGREGATIONS OF PARTICLES.

In this laboratory no evidence has been obtained to show that agitation of the virus inoculum has the effect of increasing the number of particles present, after care has been taken to ensure that the juice has been freed from cell debris. It is obvious that this precaution must be taken because masses of cytoplasm might well contain numbers of particles which would be liberated as the proteins degenerated. It has long been known that some increase does take place in juice which after maceration is allowed to stand for 24–48 hours, and it is now generally agreed that this apparent increase is due to autolysis of the tissues.

The question under consideration is, however, the disintegration of masses of virus bodies aggregated so that the mass functions as an individual particle. Two possibilities suggested themselves, (a) the virus bodies might be loosely grouped together—in which case they should be separated either by agitation or by standing, and (b) the bodies might be adsorbed in groups to a large protein molecule, in which case they would tend to separate on digestion of the protein.

The first possibility was examined first. An inoculum was prepared by macerating a quantity of tomato-leaf mosaic with twice its weight in water. This material was allowed to stand on the laboratory bench overnight. After 24 hours it was passed through a fluted filter paper impregnated with fuller's earth and the filtrate diluted to 1/50. This material was well shaken and allowed to stand for 24 hours. The first inoculation, with 0.1 c.c. rubbed on each of five leaves of two plants of *N. glutinosa*, was made 48 hours after the infected leaves had been picked.

Table IV.

Number of spots per ten leaves of N. glutinosa, inoculated with 0.1 c.c. of material after 48, 72, 96, 120 and 144 hours.

Series	Time hours	No. of spots on ten leaves	
		Exp. 1	Exp. 2
A	48	18	276
B	72	19	277
C	96	7	190
D	120	6	78
E	144	13	107

Five series of leaves, A–E, were inoculated. Each series was inoculated by rubbing in the usual way with 0.1 c.c. of inoculum 24 hours after the previous group. In the interval the inoculum has been allowed to stand in a stoppered Erlenmeyer flask on the laboratory bench, and it

was shaken at intervals. No toluol was added to reduce bacterial growth and some bacterial contamination took place. This was not very pronounced, however, and did not, apparently, greatly affect the results. The data obtained from two experiments are detailed in Table IV.

It may be seen from these results, that in these earlier experiments which are taken as representative of a group of similar experiments there is no evidence that there is any increase in the number of particles by the breakdown of groups into smaller units.

THE DIGESTION OF THE PROTEIN IN THE INOCULUM.

The other possibility to be considered was the adsorption of the virus bodies to protein molecules. This seemed not improbable in the light of the fact that protein precipitants have the effect of removing virus from infectious juices. An inoculum was prepared from tomato-leaf tissue in the usual manner. This was diluted to 1/50. Thereafter 100 c.c. were put into an Erlenmeyer flask with a cotton-wool plug. A few drops of toluol were added. This served as a control. To another 100 c.c. similarly treated was added 0.1 gm. of trypsin powder and to another a like amount of pepsin. All three were kept in an incubator at 25° C. for 24 hours. Thereafter, inoculations were made by rubbing in the usual manner 0.1 c.c. of the liquid on each of a number of leaves of *N. glutinosa*. Counts were made of the spots which developed on the leaves after a week, and the data showed that whereas there was no apparent increase or decrease in the number of spots induced by the pepsin-treated material over that induced by the control liquid, the trypsin had had the effect of reducing, in all cases very considerably, and in others actually to one or two, the number of spots found on the treated leaves. It is shown that this reduction is probably due to an adsorption of the virus to the enzyme rather than to a destruction of the virus by the enzyme. For the moment, the main interest attaches itself to the fact that destruction of the protein in no wise increases the number of the spots formed on inoculation. It therefore appears that the virus is not aggregated into masses which easily break down mechanically, nor is it adsorbed in groups on to the proteins of the plant.

THE NUMBER OF VIRUS PARTICLES PRESENT IN A JUICE.

It was thought that if certain assumptions were made in the light of the foregoing experiments, it should be possible to give an approximate idea of the number of virus particles present in any given juice. The initial concentration of juice is known; let us say that the dilution is

1/100 and that 0.1 c.c. of this juice is rubbed on the surface of a leaf of *N. glutinosa*. Let us assume further that fifty spots are formed as a consequence of inoculation. The spots are formed following the entry of the virus into a broken hair. The majority of the hairs which are broken by rubbing fracture just at the base, so, for practical purposes, it may be taken that the entry is made at a ruptured hair base. If one assumes, further, that the inoculum is evenly distributed over the surface of the leaf the number of particles which enter hair bases will be a fraction of the total number spread over the surface. This fraction will be dependent on the relation between the area of the hair bases and the surface of the leaf. Actually, in cross-section, the hairs are found to be very numerous and the hair bases occupy approximately one-third of the epidermis in a transverse section of the leaf. They are fewer over the veins and the distribution is not absolutely uniform, so for purposes of argument it is suggested that one-tenth of the leaf surface might be considered as occupied by hair bases. As has been pointed out, the ease with which hairs break varies greatly from plant to plant and from leaf to leaf, and in the same way the ease with which individual hairs on any one leaf break also probably varies considerably. It may, therefore, be necessary to make some allowance for the proportion of whole to broken hairs. To off-set this, however, there is the consideration that there is probably a tendency for more of the particles to attach themselves to hair bases than to remain on the surface of the leaf, since the bases are slightly raised above the general surface of the epidermis, and any particles being carried over the surface in a film of liquid will tend to hit the broken bases. It is suggested that it may, for purposes of this argument, be assumed that it is fair to consider that the number of particles present on a leaf surface is represented by ten times the number of the spots formed.

To revert to the supposed observation that fifty spots had been found as a consequence of rubbing 0.1 c.c. of a juice diluted 1/100, it follows, therefore, that the number of particles in the original diluted juice was

$$50 \times 10 \times 100 Y \text{ per c.c.} = 50,000 Y \text{ per c.c.,}$$

the value of Y , i.e. the proportion of virus particles which enter broken hairs on the surface of a leaf of which one-tenth of the area is occupied by hair bases, is, as we have seen, difficult of assessment but may be taken as 10, as we have suggested.

It therefore follows, if the validity of this argument be admitted, that a fair approximation to the number of particles may be arrived at by

taking the average number of spots on a given number of leaves or, alternatively, by taking the number of spots for the greatest dilution and considering the numbers obtained from them as being the maximum figure.

For example, in the experiment of November 10th, 1931, there was one spot on each of two leaves of the five. The dilution was $1/100,000$, so that the total number of particles, using the method outlined above, was $1 \times 10 \times 100,000 \times 10 = 10,000,000$ per c.c. of the original inoculum. This was made by macerating tissue with twice the weight of water, so the original tissue contained rather more than 3×10^7 particles per c.c.

THE EFFECT OF ENZYMES ON THE VIRUS AGENT.

In the experiment with trypsin and pepsin digestion outlined above it was found that whereas pepsin appeared to have no effect on the number of spots which formed after inoculation, trypsin had the effect of very much reducing the number. That this is not due to a definite destruction of the virus agent by the enzyme is indicated by the fact that heating the virus material to 70°C . for 20 min. after incubation had the effect of increasing the number of spots on subsequent inoculation to a number comparable with that formed with the control material. Both taka-diastase and malt-diastase, freshly prepared from barley, had a similar effect to trypsin of reducing the number of spots which were formed, and heating in these cases did not restore the efficiency of the inoculum. It was not possible, however, with these enzymes to destroy them, as judged by their effect on starch, without heating above 70°C . This would, at the same time, have destroyed the virus which will withstand heating to 80°C . for only a short period. At the same time, boiling the enzyme in water before treatment of the virus had the effect of rendering it innocuous. The presence of iodine in potassium iodide solution, which itself had no effect on virus numbers, was also able, with malt-diastase, to prevent the interaction of the enzyme with the virus. The possibility of the virus having a specific reaction on the tissues of the host plant was examined. It is possible to account for the reduction which occurs in these experiments with enzymes and aucuba mosaic by assuming that the enzymes react on the broken hair bases so as to prevent the entry of the virus into them. To demonstrate that this was not so, the following experiment was set up. A mixture of 0.2 gm. of trypsin powder with 20 c.c. water was made up. This was rubbed carefully over the leaves of *N. glutinosa* plants as would have been an inoculum. Thereafter, an inoculum of aucuba mosaic was also rubbed over the

treated leaves. This was further rubbed over other leaves on the same plants which had had no trypsin treatments. The amount of the inoculum was the same in both cases. The average number of spots per leaf for the trypsin-aucuba mosaic was 38 and for the controls 43. It would appear, therefore, that effect of these enzymes is to adsorb the virus and so inactivate it, rather than to act specifically upon it and break it down or to render impossible the entry of the particle into the plant tissue (cf. Holmes(6)).

THE MULTIPLICATION OF THE VIRUS WITHIN THE
TISSUES OF *N. GLUTINOSA*.

As has been pointed out above there is reason for supposing that a single virus particle of the aucuba mosaic virus will on entering a broken hair of *N. glutinosa* give rise to necrosis. From earlier experiments(3) it had appeared that the multiplication of the virus within the tissues of the *N. glutinosa* plant was not great, and in no event did the disease become systemic. The method of counting the necrotic spots induced on a leaf affords a more precise method of assessment of the amount of virus present in a tissue than does the older method of inoculation of the suspected juice into groups of healthy seedling tomatoes. The procedure adopted was to remove each spot from the leaf and a portion of the surrounding tissues with a cork borer of 5 mm. diameter. Of these discs one to five were taken and macerated in watch-glasses with the minimal amount of water 0.1–0.25 c.c. This material was rubbed on the surface of a leaf on *N. glutinosa*. As a consequence of a large number of such experiments it would appear that the number of spots which appear on the treated leaves is some 15–30 per 0.1 c.c. in the original inoculum. If one assumes that the original spot was induced by one particle and that the number of spots is indicative of one-tenth of the number of particles actually present on the leaf, then the multiplication has been of the order of 250 times. Even if a single particle were not involved in each necrotic spot but a group of particles, the same argument holds.

The multiplication would appear to be large if one had not, at the same time, examined the numbers of the virus within a disc of tissue of a leaf of a tomato plant infected with aucuba mosaic. When a single such disc was macerated in water and rubbed over the surface of a leaf of *N. glutinosa* the whole lamina became pitted with necrotic areas which were so close as to become confluent. Actually, counting on such leaves is very difficult, but the number of spots formed was of the order of 500. Since the number of broken hairs at this point has become a limiting

factor it is clear that the multiplication in the tomato tissue must be very much greater than in the *glutinosa*. Inoculations had not originally been made in the leaves from which the discs were taken, so that this multiplication had clearly taken place throughout the whole of the plant. If one makes the same assumptions as were made for the *glutinosa*, viz. that one particle first entered the disc under observation and there multiplied and that the number of particles on the *glutinosa* lamina was ten times the number of spots, the multiplication of the virus in the tomato tissue was of the order of 10,000 or more times.

DISCUSSION.

Considerable importance has been attached to the difficulty of breaking the hairs in the leaves on *N. glutinosa* when inoculations are being made with infectious juice. As has been pointed out no satisfactory method of inoculation has suggested itself which would overcome the difficulty of the non-breaking of hairs or the destruction of the mesophyll tissue. Another factor which has to be considered in the light of the results which have been obtained is the difficulty of obtaining comparable inocula from different plants and different tissues. For example, when an inoculum diluted 1/100 and lower is prepared in the usual way it is customary to find some 20–100 spots on each leaf rubbed with 0.1 c.c. From some plants, however, a dilution of this amount would give only one or two spots and would be unsuitable as a source of material for dilution experiments. What controls the amount of virus which is present in any given plant is not clear, but it would appear that intensity of symptoms in the host tomato plant is not an evidence of high virus content.

These and other considerations render almost impossible the obtaining of consistent results in every experiment. At the same time, many of the experiments have yielded results which can be shown to have a high degree of statistical significance. In other experiments, by reason of the operation of one or more of the factors indicated above, some of the data were not in accordance with expectation.

The fact that many of the experiments did yield results which indicate that the number of spots bears a direct relationship to the degree of dilution is taken to indicate that the virus is particulate and that one particle is able to set up a necrotic spot if effective entry is made into the tissues.

A simple experiment was set up to show in another way that the number of spots formed is an index rather of the number of particles

than of the number of spots at which entry into the leaf tissue can be effected. A large series of leaves were rubbed and it was found that the average number of spots induced by inoculation of 0.1 c.c. of a virus inoculum was 22.3.

A further set of leaves was inoculated with the same virus, and a third set was inoculated by rubbing the same amount of inoculum on one half of the lamina leaving the other half of the lamina clear. In this experiment, therefore, the same amount of inoculum was rubbed on two sets of surfaces, one having half the area of the other. If the number of spots formed bore any relation to the amount of surface rubbed, the leaves of which only one-half was rubbed, should have only half the number of spots. The leaves with the whole lamina rubbed had an average 22.7 spots, and those of which the half was rubbed 25.6 spots. It is clear, therefore, that the area rubbed is not the controlling factor in the formation of spots, so long as there is a sufficiently large number of broken hairs present to admit of the entry of a particle into each.

The experiments in which the juice was, before inoculation, treated with enzymes or coagulated to break up the aggregations of virus particles, if such existed, tend to show that the particles are not grouped together in the inoculum except in so far as masses of cell debris may contain numbers of particles. The cell debris was removed in every case in the experiments outlined above by filtration of the inoculum through fuller's earth.

In the calculation of the number of particles which is present in any given inoculum one or two assumptions had to be made. One was that the hairs broke fairly easily over the whole surface of the leaf, and that, therefore, the area of the hair bases could be considered as the area of the surface available for the effective entry of the virus particles. The actual area of the hair bases can be shown to be approximately one-tenth of the total area of the adaxial side of the leaf. The other assumption which had to be made was that approximately a constant proportion of the hairs was broken. This is clearly not strictly correct, but, on the other hand, there is the consideration that the chance of particles being held up by the broken hairs is probably rather large. This is a difficult question to settle definitely, but one experiment can be carried out which throws some light on the problem. Four or 5 days after being rubbed a leaf develops the necrotic spots which constitute the symptom of aucuba mosaic. During the first 3 days the greater majority of the spots have been formed and the numbers do not appreciably increase thereafter. If the spots which have been formed are "cut out" in a disc of tissue as

above described it is found that the number of particles in each appears to be of the order of 20-30. If the tissue between the spots be taken, on the other hand, and after maceration in water be used as inoculum few spots if any develop on the treated leaves. Patches of ten discs were taken, and after maceration with the minimum of water were rubbed on the leaves. In only one leaf out of ten so treated did a single spot occur. It would appear from this experiment that the "unattached" particles on a treated leaf are relatively few, since there is evidence that the aucuba mosaic virus is comparatively resistant to drying and keeping.

If similar discs of tomato-leaf tissue be taken and macerated it was found that the number of particles present is very much larger than in similar discs of *N. glutinosa* tissue. The number of spots formed on *N. glutinosa* leaves after rubbing with a macerated disc of tomato-leaf tissue amounted to hundreds. It was in most cases impossible to count the spots which number over 600 per leaf. The multiplication of the virus in the tomato is, therefore, enormously greater than in *N. glutinosa*.

SUMMARY.

In this paper the symptoms of aucuba mosaic of tomato in *N. glutinosa* are described. A method is discussed whereby it is possible to count the spots formed after inoculation with juice diluted to different strengths. The fact that the number of spots formed is proportional to the amount of dilution is taken as indication of the particulate nature of the virus. A method is suggested for counting the number of virus particles present in a juice. It is shown that the amount of virus present in a juice does not increase after agitation or after treatment with proteolytic enzymes. With trypsin and diastase they were decreased. This decrease, it is suggested, is due to the adsorption rather than to the destruction of the virus. The amount of multiplication of the virus in the tissues of *N. glutinosa* is examined and compared with the much greater multiplication in tomato tissues.

This work was carried out under the auspices of the Empire Marketing Board.

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(Received July 11th, 1932.)

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THE DEVELOPMENT OF ASSIMILATORY TISSUE IN SOLANACEOUS HOSTS INFECTED WITH AUCUBA MOSAIC OF TOMATO

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(With Plates VII-IX.)

CONTENTS

	PAGE
I. Introduction	57
II. Material and methods	58
(1) Vital methods	58
(2) Fixing and staining methods	58
III. Development of chloroplasts in normal plants	59
IV. Chloroplasts of diseased plants	62
V. Intracellular inclusion bodies	65
VI. Summary	66
References	67
Explanation of Plates	68

I. INTRODUCTION.

AUCUBA mosaic of tomato produces on the leaves of a number of Solanaceous hosts a vivid yellow mottling⁽¹³⁾. The cells of the yellow areas are found to be practically devoid of chloroplasts, but it was not known how this condition arose. As this distinct mottling is confined to those leaves which were in active growth at the time of inoculation or which are produced later, it seemed unlikely that the plastids are destroyed, but rather that their development is in some way inhibited. The mode of origin of plastids in higher plants has long been a controversial point: it was therefore necessary to examine the normal course of development of the plastids before any attempt could be made to discover how the conditions existing in the diseased leaves are brought about.

Many virus diseases are characterised by the production in the cells of the host of abnormal inclusion bodies. In several Solanaceous hosts infected with aucuba mosaic of tomato, these bodies are built up by the gradual agglomeration of minute protein particles which appear in the

cytoplasm soon after infection⁽¹²⁾. It was not known whether these bodies are present in the primary meristem. If they are present it would be interesting to know what is their behaviour at cell division.

Both the question of plastid development and that of the formation of intracellular inclusions involved an examination of the younger tissues of the shoot, and so work on the two problems was carried on more or less concurrently.

II. MATERIAL AND METHODS.

Three host plants, *Solanum nodiflorum*, *S. lycopersicum* and *Nicotiana tabacum*, were studied. Seedlings were infected with aucuba mosaic by leaf mutilation. The minute structure of these three hosts is identical and they are similar in their reaction to the virus disease; they will therefore be dealt with together.

Of the two problems mentioned above, work on the second, that of the virus inclusion bodies, was actually commenced before the former problem developed. Some of the methods employed to study intracellular inclusions were not applicable to the work on plastid development, and others had to be modified when this problem came under consideration.

(1) *Vital methods.*

In order to examine the young growing tissue of the shoot the material was sectioned, sometimes by hand but, more usually, by a freezing microtome. Sections were cut first at a thickness of 10μ for intracellular inclusion bodies and later, when a special study of the plastid development was being made, at 5μ . Sections were mounted in an isotonic sugar or salt solution. The results obtained by the study of living material were very disappointing. Owing to the rapidity with which death occurs in sectioned material, only a very cursory examination could be made. Also, in the living cells it is difficult to distinguish between plastid primordia and other granular cell inclusions and, as Randolph⁽¹⁰⁾ and Zirkle⁽¹⁹⁾ found, vital stains are of very little use. Recourse has therefore to be taken to more orthodox cytological technique.

(2) *Fixing and staining methods.*

Fixatives such as Zenker's and Flemming's fluids gave well-preserved nuclei and virus inclusion bodies in the younger plant tissues. Preparations from material fixed in this way were stained with Feulgen's fuchsin sulphurous acid stain and counter-stained with orange G, methyl blue or light green.

Although mature plastids are preserved, their primordia are destroyed by fixatives containing acetic acid; the latter are, however, preserved by bichromate mixtures. For the preservation of minute cytoplasmic inclusions, a number of methods were tried. These included Flemming's fluid without acetic acid, Altmann's fixative, osmic acid, Champy's solution and Champy followed by osmic impregnation. No perfect fixation over a whole preparation is ever obtained, for the degree of excellence varies greatly in tissues differing only slightly in development. The most generally reliable results were given by Champy's mixture, and this was used principally. The nuclei were not well preserved, but the proplastids and, when present, the virus inclusion bodies were quite well fixed.

The stem tips surrounded by a few of the youngest leaves were immersed in alcohol immediately on cutting from the plant to remove air held by the hairs and between the leaves. After 1 min. they were transferred to the fixing solution and the remaining air was removed with a suction pump. After all air was exhausted from the material the fixing solution was renewed, since volatile constituents such as osmic acid tend to be lost as the air is drawn off. The material was fixed for 24 hours and was then washed for a similar period in running water: it was dehydrated in alcohol, cleared in cedar-wood oil and embedded in 52° C. paraffin wax. Some sections were cut at a thickness of 10 μ for intracellular inclusion bodies, but thinner sections are of more value for the study of plastid development. Most of the material was cut therefore at 5 μ . A number of stains were used: Altmann's aniline fuchsin differentiated with picric acid and Haidenhain's haematoxylin gave the clearest preparations.

III. DEVELOPMENT OF CHLOROPLASTS IN NORMAL PLANTS.

The plastids can be traced back to a group of minute bodies present in the primary meristem of the shoot, which in plants of each of these three species consists of a number of small undifferentiated cells separated by very delicate walls with no intercellular spaces. Each cell contains a large nucleus embedded in the cytoplasm. The cytoplasm practically fills the cell, the few vacuoles which are present being quite small (Plate VII, fig. 1 and Plate IX, fig. 1). It is this lack of vacuolation and the fineness of the cell walls which render the young growing tissues so much more easily fixed than adult tissues.

Even at this early stage certain minute inclusions are present in the plasm and can be viewed in the living tissue. In each cell is a large number of minute slightly elongated granular bodies which are of the

order of 0.1μ in diameter (Plate VII, fig. 1 and Plate IX, fig. 1). They are of a highly reactive nature and consequently are easily destroyed in the processes of fixation and embedding. Normally they are preserved only by bichromate mixtures such as Champy's fluid. They stain black with Haidenhain's haematoxylin and red with Altmann's aniline fuchsin. It is to some of these bodies that the origin of the chloroplasts can be traced. It now seems fairly well established that plastids in the higher plants are formed either from chondriosomes or from bodies strongly resembling them. The literature has been frequently and ably summarised (5, 8, 11, 16, 17), and does not need to be discussed here. These minute cytoplasmic inclusions present in the cytoplasm of the cells of the primary meristem appear to be all identical and can be differentiated neither by their form nor by their chemical reactions. No evidence was forthcoming to indicate whether certain of these bodies are pre-ordained to develop into chloroplasts or whether their further development is a matter of pure chance.

An ergastic substance is often found in these tissues (Plate IX, fig. 2), but it is sharply differentiated from the primordia or chondriosomes by its chemical reactions. It takes the form of globules which vary considerably in size, the smallest being of the same order as the plastid primordia. The globules are particularly abundant in the epidermal cells, but are usually absent from the more deeply seated tissues. They are highly refractive and are preserved alike by acetic and bichromate mixtures which render them insoluble during the processes of dehydration, clearing and embedding. They stain black with Haidenhain's haematoxylin, yellow with Altmann's stain, green with aniline fuchsin methyl green, yellow with Feulgen and orange G, green with Feulgen and light green. They blacken with osmic acid, with Sharlach R they give a pink coloration and a faint pink reaction with Millon's reagent. They appear to be oil bodies of the nature of a food substance. In slightly older tissue they disappear.

Cell division in the meristem is frequent and rapid. Prior to each mitosis the cytoplasmic inclusions become segregated into two groups, one around each pole of the spindle, so that roughly half of the bodies are included in each daughter cell. It was not known whether the chondriosomes themselves divide or whether they arise *de novo* in the plasm. No direct evidence of division was obtained, although a paired arrangement, suggesting division, is often seen.

After active cell division ceases the cells, having become differentiated to form the various tissues of the leaf, increase in size. At the same time, the primordia of the chloroplasts also begin to increase in size in those

cells which are destined to become assimilatory tissue (Plate VII, figs. 2-3). Soon a small vacuole appears in the centre of each primordium or, if the primordium is a slightly elongated one, the vacuole may appear towards one end (Plate VII, fig. 4 and Plate IX, fig. 3). These bodies rapidly increase in size and now fix as small spheres with a large central vacuole and a dark staining periphery (Plate VII, fig. 5). About this time a slight pigmentation of the peripheral layer can sometimes be seen in living tissues. The vacuole contains a starch grain which cannot ordinarily be seen in fixed preparations, as the index of refraction of the starch is almost the same as that of the mounting medium. In the living cell, however, the grains give a dark coloration with iodine and show the characteristic starch structure if examined in polarised light. The proplastid continues to increase in size and minute pores appear in the dark staining stroma which surrounds the starch grain. Thus communication is established between the central vacuole and the exterior of the plastid (Plate VII, fig. 6). Throughout its development the plastid gradually becomes more and more resistant to chemical reagents, and some time before it reaches maturity it is capable of being preserved by acetic as well as by bichromate mixtures.

The development of the plastids of these Solanaceous plants conforms very closely to the mode of development of the plastids in a number of other higher plants including *Elodea canadensis* (18), *Zea mays* (10, 18, 19) and *Pisum* (9).

The plastids have now assumed the form of the type chloroplast of the higher plants described and figured by Zirkle (17), part II, Plate XXVII, fig. 45). Each is a hollow body, spherical or ellipsoidal in form. Within the central vacuole is a starch grain: two or even three grains may appear later (Plate VII, figs. 6, 7). The vacuole is enclosed by a pigmented stroma which takes a deep stain and which is penetrated by innumerable minute pores. The plastids are embedded in the cytoplasm, usually in the layer which lines the cell wall.

A mature plastid is of the order of 5μ in diameter. The size may vary with the amount of starch contained, and sometimes they swell so as to form an almost continuous layer at the periphery of the cell. If much swelling occurs the stroma forms merely a dark staining meshwork around the starch grain. Mature chloroplasts occasionally divide (Plate VII, fig. 8), but no direct evidence of division prior to this stage was obtained. A paired arrangement (Plate VII, fig. 2) of the plastid primordia was frequently observed and may result from division.

The development of the plastids is not intimately bound up with the

development of the cell, indeed, proplastids of many different stages may be found in the same cell. Their development usually commences as the cells become differentiated. In a young leaf the cells towards the lower surface, that is the spongy tissue, are often further advanced in development than those towards the upper surface which are destined to become palisade cells. Usually the plastids in the lower cells are more advanced than those in the upper undeveloped cells: this may be due to the relatively larger amount of light received by the ventral surface of the leaf at this stage. The plastids in the palisade cells may be fully developed before the cells elongate, but at other times quite young primordia are found in elongated cells. Plastid development is often further advanced towards the tip of the leaf which, again, is probably due to the larger amount of light received. Although, generally, the more advanced cells contain more fully developed plastids no rigid law is adhered to.

IV. CHLOROPLASTS OF DISEASED PLANTS.

When a plant becomes infected with *aucuba* mosaic a yellow mottling appears on those leaves which are in active growth at the time of inoculation and on leaves which are developed subsequently. These yellow areas are almost devoid of chlorophyll. Older leaves may show a certain amount of yellowing, possibly due to ageing of the plastids, but the distinct mottling never appears on leaves which are fully developed at the time of inoculation.

In section the differences between green and chlorotic areas are striking. A section through a green area, apart from intracellular inclusion bodies which may be present (p. 65), appears exactly like a section of a normal leaf. The green parts of the leaf contain several layers of palisade tissue, packed with chloroplasts, and below, several layers of spongy parenchyma also containing an abundance of green plastids (Plate IX, fig. 4). A section through a yellow area may show a few isolated cells filled with quite normal chloroplasts, but the majority of the cells are entirely devoid of plastids (Plate IX, fig. 5). The cells may be of the same size as those of the green areas, but more usually they are smaller. Often the palisade cells are not elongated at all and there are no intercellular spaces between parenchymatous cells. In these extreme cases, the chlorotic areas of the leaf are much thinner than are the green parts. The cells of the yellow areas often seem to contain more than the normal amount of cytoplasm.

Certain previous workers have stated that the plastids are destroyed by the virus, and an organism resembling a protozoon has been figured actually entering the plastids of plants with tomato mosaic(2). In

another paper the gradual dissolution of the plastids of diseased plants is described (15). The latter results would be more convincing if confirmed by the use of different technique, as the phenomena described might be brought about by keeping the sections in water for prolonged periods. Such treatment invariably causes the precipitation of hyaline spheres from the cell sap even in the abundance in which they are described in the hairs. Chloroplasts from normal plants if mounted in water soon swell up, each forming a large hyaline vesicle which may burst, or a number of them may form a state of equilibrium in the cell. As aucuba mosaic does not affect the chloroplasts of leaves which are fully developed at the time of infection, it seems unlikely that mature plastids are destroyed by the virus. The mottling of only young growing leaves suggests that the virus prevents the formation of plastids, and this has been found to be the case.

The meristematic tissue of diseased plants appears to be like that of healthy plants. Nuclear division is normal as is the structure of the cells. When cell division ceases the plastid primordia of certain of the cells begin to increase in size, and all stages in development of the plastids can be seen to occur exactly as in the normal plants (Plate VIII, figs. 1, 2; Plate IX, figs. 7, 9). But now other cells are seen to be devoid of proplastids. Sometimes a few minute dark-staining inclusions which may be either chondriosomes or primordia are present, but they do not develop further (Plate VIII, fig. 3 and Plate IX, fig. 9). It is evident that the virus has inhibited the development of the primordia and in many cases has completely destroyed them.

Various conditions are found within the adult cells of a diseased leaf. We will omit for the moment the question of intracellular inclusions caused by the virus. The cells of the green areas appear like those of the normal plants, but in the chlorotic areas cells may be of normal size and contain a few plastids and occasionally a few primordia or chondriosomes; they may be of normal size, containing no plastids but possibly a few undeveloped primordia; or they may be small when usually they contain primordia. The actual condition of the cells of a diseased leaf probably depends on the exact stage of development which has been attained when the virus reaches the cell in sufficient concentration to affect development. If the vacuolation of the primordia has commenced before the attack of the virus then it is very rarely that its further development is in any way affected. Occasionally proplastids of this stage are affected as is shown by the presence together in adult cells of bodies which may be chondriosomes or primordia, developing proplastids and very small mature plastids (Plate VIII, fig. 4 and Plate IX, fig. 8). If the virus reaches the

cell before plastid development has commenced, then the development of the plastids is inhibited and usually they are destroyed. Also further enlargement of the cell is prevented.

It has already been stated that the development of the plastids in the normal plants is not intimately bound up with the development of the cell (p. 61). For instance, plastid development may occur in a palisade cell before the cell commences to enlarge or it may not begin until the cell has elongated considerably. Thus in an infected plant sometimes palisade cells are found not to develop at all and in others the cells, although much elongated, are devoid of plastids. Further, a cell may contain primordia of several stages and, if this is attacked by virus, only the more advanced may complete their development.

The cells towards one side of a diseased leaf may be undeveloped, whilst those towards the other side are large and contain plastids. When this occurs it is almost invariably the upper cells which are affected. Presumably this is due to the fact that plastids develop earlier towards the lower side of the leaf. By the time the virus reaches the particular area of the leaf, the proplastids in the lower cells may be quite advanced, although those in the adjacent upper cells are still minute primordia which are easily destroyed by the virus.

Chondriosomes and plastid primordia are identical in all their reactions so far as can be observed. There is no evidence that they are not actually identical, it being a matter of chance which chondriosomes develop into plastids. It is not surprising that they react as readily as they do to the virus, since the chondriosomes of many plants and animals are known to react very readily to all kinds of cell injury (3). The reaction of the chondriosomes or primordia to the virus appears analogous to their reaction to chemical substances. It is just at the stage that they begin to become resistant to fixatives that they are usually unaffected by the attack of the virus. It has been suggested that the virus causes an increased acidity in the host tissues (1) and, in this connection, it is worthy of note that it is the fixatives of lower pH value which destroy the primordia most readily.

It should be emphasised that no evidence whatever was found of the destruction of mature plastids. Very occasionally the development of proplastids is inhibited during its course, but usually if a primordium is not destroyed or its development inhibited in a very early stage, then it will give rise to a perfectly normal chloroplast. Those primordia whose development is not inhibited behave in all ways as do those of the normal plant. In mature palisade cells the chloroplasts lie at the periphery. Occasionally they have a tendency, even in the normal plant, to become

swollen, when they tend to form a complete layer within the cell wall. In diseased plants this tendency has been found, occasionally, carried to an extreme, plastids becoming so swollen with starch that they actually fill the cell, their pigmented stroma forming a meshwork between the grains (Plate VIII, fig. 5). This was the only abnormal behaviour seen in the mature plastids of plants with aucuba mosaic, and it is not established that it may not occur also in healthy forms.

V. INTRACELLULAR INCLUSION BODIES.

In a number of Solanaceous hosts including *Solanum nodiflorum*, *S. lycopersicum* and *Nicotiana tabacum* infected with aucuba mosaic, the first symptom of the disease to be evident in the adult cells is the accelerated streaming of the cytoplasm. Minute protein particles appear in the plasm which carries them passively about the cell. These particles aggregate and fuse and, in the course of a few days, a large inclusion body is built up (12). Protein inclusion bodies have been described as associated with a number of virus diseases of both plants and animals. In tobacco with mosaic disease, they are present in the meristem where they are thought to divide prior to nuclear division (4). No inclusion bodies could be found in the meristematic tissue of plants infected with aucuba mosaic. Their formation does not commence until after cell division has ceased and, when present, they are invariably formed by the aggregation of small particles. Those minute cytoplasmic inclusions, the chondriosomes, are swept into the body as it is formed and can be seen in preparations suitably fixed and stained (Plate VIII, fig. 6 and Plate IX, fig. 6).

The bodies are not confined to the chlorotic areas of the leaf but are formed equally abundantly in green and yellow tissues. They are particularly abundant in the hairs of the leaves of all three hosts, being present in practically every cell. Localised areas of epidermal cells containing bodies, occur in both green and yellow tissues. Very occasionally a few adjacent palisade or spongy parenchyma cells below the affected epidermis may contain bodies. This apparent random distribution of the bodies over chlorotic and "healthy" areas was not understood (12). If the virus was present in sufficient concentration to cause the production of bodies it seemed strange that the plastids could withstand it and if plastid development was inhibited why did the virus not of necessity cause the production of bodies? The apparent anomaly is explained by the delay in the formation of bodies until after the plastids are developed. The young cell responds in several ways to the virus attack. Cell growth is inhibited, simultaneously the proplastids are destroyed or their

development prevented and, later, intracellular inclusions may be formed. If plastid formation is not inhibited at a very early stage, normal plastids will be formed and persist even if the virus reaches the cell at a later stage. But the virus may not reach a cell until after its growth is almost complete and the plastids have become resistant: in such a case inclusion bodies may be formed although the plastids are unaffected.

It is difficult to account also for the relative prevalence of these inclusion bodies in tegumentary tissues and their rarity in the parenchyma. It was thought possible that their formation might be to a certain extent controlled by the *pH* of the cell contents. An attempt was therefore made to determine the relative acidity or alkalinity of the different tissues, Small's technique (7, 14) being followed. The method is not sufficiently delicate to give absolute values for such fine structures, but it was thought that certain tissues might be found to be more or less acidic than others. The results obtained were disappointing: there was very little differentiation between the tissues, although the tegumentary tissues tended to have a very slightly lower *pH* value than the other tissues. Differences between different hosts were marked, but no differences were found between healthy and diseased plants.

VI. SUMMARY.

The development of the chloroplasts in *Solanum nodiflorum*, *S. lycopersicum* and *Nicotiana tabacum* is described and comparisons are made with plants infected with aucuba mosaic.

In the normal plants after cell division ceases in the meristematic tissue certain minute bodies, which are present in the cytoplasm of all young cells, commence to enlarge. A vacuole is formed in each and this gets bigger as the proplastid increases in size. A starch grain is formed in the vacuole. The outer stroma becomes pigmented and pores are formed in it. Increase in size continues, the mature plastid being about 5μ in diameter. A second or third starch grain may be formed in the vacuole. Chloroplasts sometimes divide.

In plants infected with aucuba mosaic certain of the leaf tissues are devoid of plastids and the cells may be undifferentiated. The absence of chlorophyll is brought about by the inhibition by the virus of the development of the plastid primordia. Usually the primordia are destroyed. If plastid development is not prevented in a very early stage, perfectly normal plastids are formed. Mature plastids are never affected by the virus but occasionally intermediate stages may be.

Intracellular inclusion bodies are not found in meristematic tissue, but incipient bodies appear when the cells are increasing in size and after plastid development is well advanced. For this reason inclusion bodies are formed indiscriminately in green and chlorotic areas, the virus presumably having reached the green tissues too late to inhibit plastid development.

An attempt was made to determine whether the prevalence of intracellular inclusion bodies in tegumentary tissues and their rarity in assimilatory tissues is due to differences in the pH of the tissues but the results obtained were rather indefinite.

This work was carried out under the auspices of the Empire Marketing Board.

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EXPLANATION OF PLATES VII—IX.

The figures of Plates VII and VIII were sketched at table level with the aid of a Zeiss camera lucida. A Leitz apochromatic 2 mm. objective (N.A. 1.4) was used in combination with Leitz periplanat oculars. For Plate VIII, fig. 5, a 10 \times ocular was used giving a magnification of 1680 \times and for fig. 6, a 6 \times ocular gave a magnification of 1000 \times . All other drawings were made using a 15 \times ocular, a magnification of 2350 \times being obtained. All drawings are reproduced without reduction.

Objects are shaded in the drawings according to the plane in which they lie: usually those in top focus are black whilst those in lower foci are successively paler.

For most of the photomicrographs of Plate IX, a Leitz 2 mm. apochromatic objective (N.A. 1.4) was used in combination with Leitz compensating oculars 6 \times or 10 \times . Magnifications were further controlled by adjustments of the bellows of the camera. For figs. 4 and 5, a Leitz 6 L objective was used.

After each description is given, in brackets:

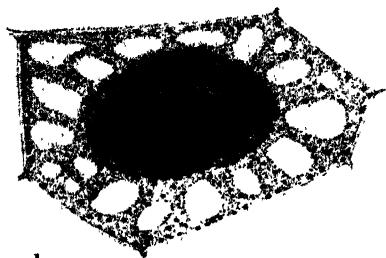
- (a) the fixative used for the preparation;
- (b) the stain used for the preparation;
- (c) the thickness of the section;
- (d) the magnification.

The following abbreviations are used:

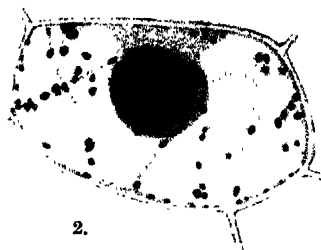
Ch. = Champy's fluid. Fl. = Flemming's fixative. F.P. = Aniline fuchsin destained with picric acid. H.H. = Haidenhain's haematoxylin.

PLATE VII.

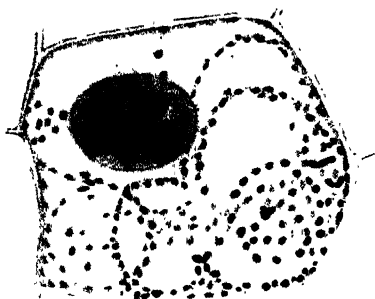
- Fig. 1. *Solanum nodiflorum* healthy. Cell from meristem showing large nucleus and minute inclusions in the cytoplasm. (Fl. without acetic acid, H.H., 10 μ , 2350 \times .)
- Fig. 2. *S. nodiflorum* healthy. Cell from young leaf. Cell division has ceased and the minute cytoplasmic inclusions are enlarging. (Ch., H.H., 10 μ , 2350 \times .)
- Fig. 3. *S. lycopersicum* healthy. A similar stage to fig. 2. (Ch., H.H., 10 μ , 2350 \times .)
- Fig. 4. *S. nodiflorum* healthy. Vacuolation and enlargement of the proplastids in leaf cells. (Ch., H.H., 5 μ , 2350 \times .)
- Fig. 5. *S. nodiflorum* healthy. Cell containing proplastids in many stages of development. (Ch., H.H., 10 μ , 2350 \times .)
- Fig. 6. *S. lycopersicum* healthy. Young palisade cell containing small chloroplasts. Each consists of a hollow green sphere, containing starch in the vacuole. The stroma is porous. (Ch., H.H., 10 μ , 2350 \times .)
- Fig. 7. *S. lycopersicum* healthy. Mature chloroplasts showing minute pores in outer green stroma and starch grains contained in the central vacuole. The lowermost plastid was sketched in middle focus. (Living, unstained—2350 \times .)
- Fig. 8. *S. lycopersicum* healthy. Mature chloroplasts about to divide. The stroma has formed a meshwork owing to its porous nature and shrinkage in fixation. (Ch., H.H., 5 μ , 2350 \times .)



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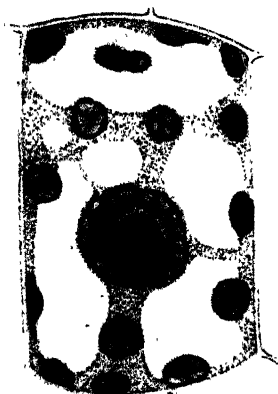
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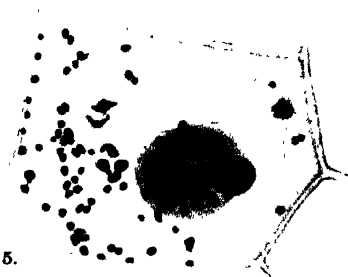
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4.



5.



6.

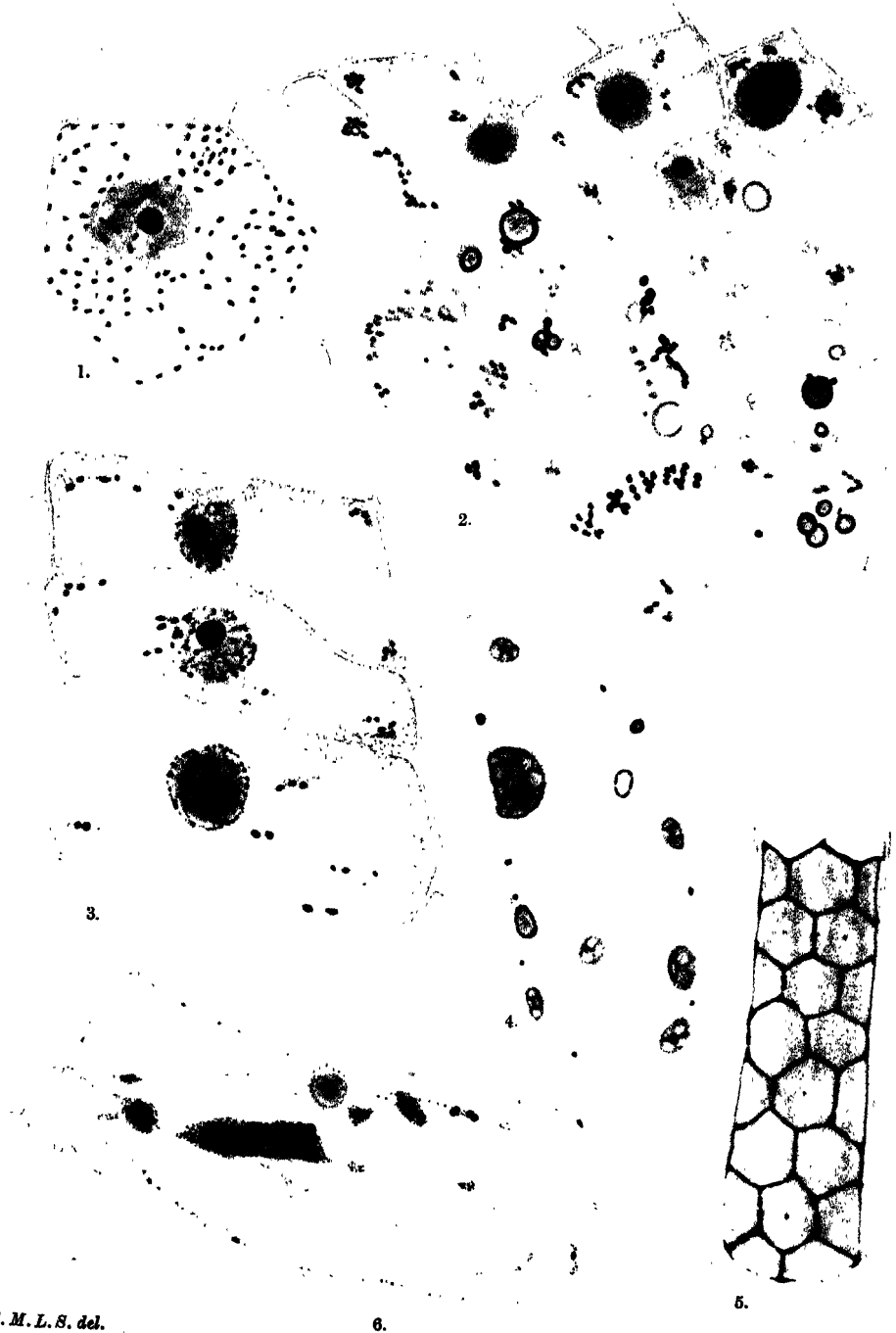


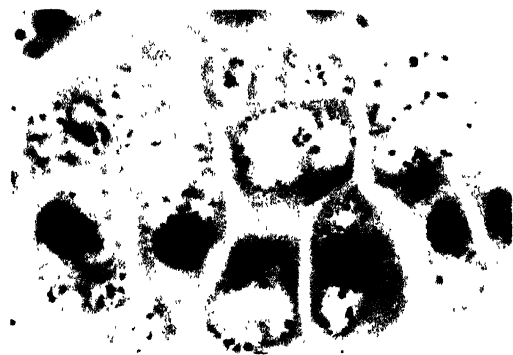
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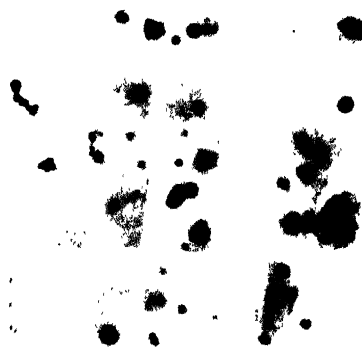
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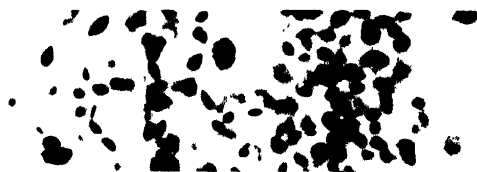




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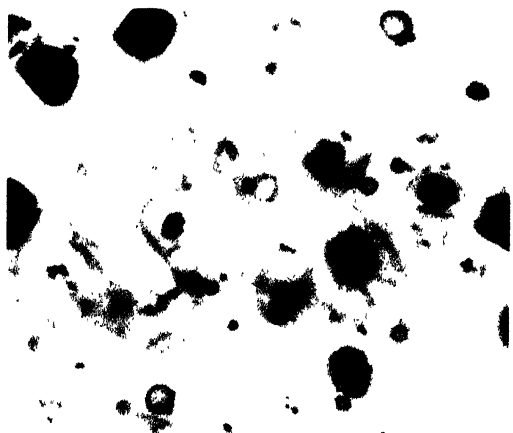
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PLATE VIII.

- Fig. 1. *S. lycopersicum* with aucuba mosaic. Cell from young leaf. Karyokinesis has ceased, the cell and its minute cytoplasmic inclusions are enlarging. (Ch., F.P., 10μ , $2350\times$.)
- Fig. 2. *S. nodiflorum* with aucuba mosaic. Vacuolation and enlargement of proplastids in young cells of leaf. (Ch., F.P., 10μ , $2350\times$.)
- Fig. 3. *S. nodiflorum* with aucuba mosaic. Palisade cells from yellow area of leaf. There are no chloroplasts but the cells contain a few small cytoplasmic inclusions. (Ch., H.H., 5μ , $2350\times$.)
- Fig. 4. *S. nodiflorum* with aucuba mosaic. Cell from young leaf containing young plastids and also proplastids whose development has been inhibited. (Ch., H.H., 5μ , $2350\times$.)
- Fig. 5. *S. nodiflorum* with aucuba mosaic. Part of abnormal palisade cell. The chloroplasts are swollen with starch and fill the cell. (Ch., H.H., 5μ , $1680\times$.)
- Fig. 6. *S. nodiflorum* with aucuba mosaic. Intracellular inclusion body in process of formation in cell from hair of leaf. Several masses of material containing protein particles and chondriosomes are suspended in the cytoplasm. Later these masses will all fuse together. (Ch., F.P., 5μ , $1000\times$.)

PLATE IX.

- Fig. 1. *S. lycopersicum* healthy. Cells from young leaf showing minute inclusions in cytoplasm. (Ch., H.H., 5μ , $1460\times$.)
- Fig. 2. *S. nodiflorum* healthy. Axil of very young leaf showing oil bodies in epidermis of stem and leaf. (Fl., H.H., 5μ , $700\times$.)
- Fig. 3. *S. nodiflorum* healthy. Development of proplastids. Same field as Plate VII, fig. 4. (Ch., H.H., 5μ , $1460\times$.)
- Fig. 4. *Nicotiana tabacum* with aucuba mosaic. Transverse section of green area of young leaf. (Ch., H.H., 5μ , $300\times$.)
- Fig. 5. *N. tabacum* with aucuba mosaic. Transverse section of chlorotic area of same leaf as fig. 4. (Ch., H.H., 5μ , $300\times$.)
- Fig. 6. *S. nodiflorum* with aucuba mosaic. Intracellular inclusion body in hair cell. The body contains chondriosomes. (Ch., H.H., 10μ , $700\times$.)
- Fig. 7. *S. nodiflorum* with aucuba mosaic. Developing proplastids in young leaf. Plate VIII, fig. 2 shows part of this field. (Ch., F.P., 10μ , $1460\times$.)
- Fig. 8. *S. lycopersicum* with aucuba mosaic. Undeveloped plastid primordia, proplastids whose development has been suspended and small plastids all present in same cell. (Fl. without acetic acid, H.H., 5μ , $1460\times$.)
- Fig. 9. *S. nodiflorum* with aucuba mosaic. Palisade cells, devoid of plastids, from chlorotic area of leaf. (Ch., H.H., 5μ , $1460\times$.)

(Received June 20th, 1932.)

STREAK IN TOMATOES ASEPTICALLY GROWN

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THERE has long been a theory that viruses may be filterable invisible stages in the life history of visible non-filterable bacteria. The idea is plausible in itself, and agrees well with the curious fact that in one or two cases specific bacteria are regularly found associated with particular virus diseases. The best instance is perhaps the well-known case of swine fever or hog cholera, a virus disease from which *Bacillus suispestifer* can be isolated so regularly that it was at one time believed to be the cause of the disease. But while facts of this sort are suggestive, there has been no direct evidence in favour of the theory. Recent work has made it increasingly probable that many bacteria can and do have filterable forms from which the original non-filterable organisms can again be obtained, but I know of no established case in which there has been obtained from a virus disease a bacterium capable, in either its filterable or non-filterable state, of reproducing the virus disease again. There has always been the possibility, even the likelihood, that the associated bacteria are secondary invaders which find in the virus-affected hosts a soil peculiarly adapted to their requirement.

The usual method of investigating this problem has been to begin with the virus-holding material, isolate from it, if possible, bacteria, and then endeavour to reproduce the disease with these organisms or obtain from them filterable material capable of reproducing it. There is in the literature of plant pathology one case recorded in which it was claimed that from a virus disease were regularly isolated bacteria capable of reproducing the disease. This is the streak or stripe disease of tomatoes, from which Paine and Bewley⁽¹⁾ isolated the organism *B. lathyri*, and believed that this bacillus on re-inoculation into tomatoes again produces the streak. But this has not been confirmed by other workers, and it is doubtful whether the authors would now be prepared to maintain their contention, at least as regards *B. lathyri*. It is, however, the fact that from tomato streak it is possible regularly to isolate specific bacteria, and it seemed worth while to approach the question from a different angle, inverting the usual method of investigation. It seemed possible to grow tomato plants aseptically from sterile seed, to inoculate these

aseptic plants with bacteriologically sterile virus-holding material and, when the disease was fully established, to ascertain whether the diseased plants contained the associated organisms. If they did, it would be good evidence that the bacteria had arisen from the virus. The following pages are a brief record of experiments carried out with this object.

Tomato streak is a disease characterised by extensive necrosis, which takes the form of black spots, often confluent, upon the leaves, and typically by black streaks upon the petioles and stems, where they may attain a length of 2 in. or more; it is usually accompanied by considerable mottling or patchy chlorosis on the leaves. It is a characteristic virus disease, transmissible by filtered juice and transferable to other Solanaceous hosts, notably to tobacco when it may be exceedingly destructive and is often accompanied by extensive and spreading necrosis of the pith. Bacteriological investigation of the necrotic tissues regularly yields bacteria of two main types, a white type and a yellow. There frequently also occurs a red yeast, but with this no detailed work was carried out, beyond ascertaining that it was not pathogenic on inoculation.

In view of the negative results obtained in the main object of the experiments only a short account of the white and yellow organisms will be given here. When first isolated, the white organism is a long, slender, markedly banded rod with ends that are often tapering. It grows freely on ordinary standard broth agar at 25° C., producing on plates large white dense slimy colonies, which tend to coalesce and grow over the whole surface; on slopes the slimy growth runs down the tube and accumulates at the bottom. This is the characteristic type regularly obtained on first isolation; but on culture there arises from it a second form, growing more slowly and producing smaller colonies with dry wrinkled surfaces and not tending to coalesce. This second form frequently appears at the margins of the mucoid growth, and may give it the appearance of having a dry feathered edge. It reverts quickly to the mucoid type, but by repeated selection can be so far stabilised that it remains true to type for several sub-cultures; it always, however, in our experience eventually produces again the mucoid type, which by its more rapid growth swamps the dry form in the cultures. In broth the mucoid type grows well, forms considerable deposit and a surface scum. At first the individual organisms are very long and banded, but after 8-14 days shorter forms appear, and the margins of the scum take on a dry wrinkled appearance. Occasionally on plates covered with mucoid growth, small papillated colonies develop, dark to transmitted light. All

these types are mycobacteria, with the usual characters of the group, converting phenol, growing on tap water and mineral salt agars, and producing the typical branched dendritic growth when the food supply is scanty or ill-balanced. In tomato juice which had been steamed, filtered, and sterilised by autoclave or repeated steaming, these organisms produce at the margin of the liquid small dark brown nodules, firmly adherent to the glass (cf. Bewley(2)). These have a crystalline structure and are of striking appearance. They are particularly well seen on tomato-juice agar, a colony being often surrounded by a ring of these nodules below the surface of the agar. They are not characteristic of these organisms, and can be produced in tomato extract by many bacteria (e.g. by many soil organisms) and some fungi (e.g. *Penicillium*). They would seem to be compounds of magnesium and calcium with fatty acids, and analogous to the bodies described by Laidlaw(3).

The yellow organisms, short bacilli, also form a small group of apparently closely related types. Although similar none was identical with any of the several strains of *B. lathyri* I was able to procure, and these so-called *B. lathyri* strains differed from one another in sugar reactions and other ways. They were obtained very regularly from the necrotic tissue, occasionally in pure culture but more commonly in association with the white organisms, and in the latter case they did not appear on the plates for 7-10 days, by which time the mycobacteria had usually covered most of the surface. On two occasions it has happened that from a piece of pith rubbed over an agar slope and left in the condensation water no growth developed for 35 days, but then the yellow bacteria grew out from the pith, and were readily sub-cultured. They are capricious in culture, and it is not unusual to have one plate covered with the small translucent smooth colonies and a duplicate plate without any growth at all.

Tomato seeds were sterilised by immersing them singly in 95 per cent. alcohol for 3 min., and then, after three washings in sterile distilled water, in a solution of mercuric chloride (1 gr. HgCl_2 , 500 c.c. water) for 12 min., during which they were repeatedly shaken. They were then washed in four changes of distilled water, and transferred with aseptic precautions to 2000 c.c. Erlenmeyer flasks stoppered with cotton-wool and covered with loosely fitting paper caps. Each flask contained a nutrient agar consisting of 700 c.c. of Brenchley's water-culture medium (KNO_3 , 1 gm.; KH_2PO_4 , 0.3; K_2HPO_4 , 0.27; MgSO_4 , 0.5; NaCl , 0.5; CaSO_4 , 0.5; Fe_2Cl_6 , 0.04; distilled water 1000 c.c.) and 7.5 c.c. agar, and had been sterilised in the autoclave the previous day. The seeds were

transferred singly, and inserted at the edge between the agar and the glass, care being taken that they lay at or only just below the level of the agar. Four or five seeds were put in each flask, which was then placed in the glasshouse. The treatment did not invariably sterilise all the seeds, and controls of 30-50 seeds in batches of five were always set up in Dunham's solution. The presence of infection on the seeds or contamination during the manipulations revealed itself by growth on the agar while the plants were developing; infected flasks were rejected, and were few at this stage.

Germination occurred after an interval which varied in different experiments from 5 to 16 days, a great delay compared with the 3-day period usual with untreated seeds, but was fairly complete, 80-90 per cent. of the seeds growing into plants. The plants grew well, though slowly, and after 5-7 weeks had three to four well-developed leaves and were ready for inoculation. This is difficult, and various methods were tried. The technique eventually adopted was as follows. Virus-holding juice from infected plants was filtered first through paper-pulp, then through an L_1 Pasteur-Chamberland candle, then through an L_3 candle, and was distributed in test-tubes in 5 c.c. volumes. The bacteriological sterility of the juice was tested by incubating some of these tubes, and by inoculation to broth. Scissor-shaped forceps with very long arms and broad blades had the blades covered with cotton-wool, and were sterilised in the dry oven. A pair of such forceps was inserted into a tube of virus juice until the wool was well moistened, then one or more leaves of each plant in a flask were crushed between the blades, one plant in each flask being left uninoculated. This method was quite satisfactory in effecting inoculation, but with the facilities available it was difficult to carry out aseptically, and the proportion of flasks infected was very high. The process of crushing the leaves required that each flask was open to the air for several minutes. Further, the flasks remained in the warm moist conditions of the glasshouse for 8-10 weeks or even more from the time the seeds were sown to the time the plants were removed for examination, and it was evident that in some cases contamination had occurred by passage through the cotton-wool plugs. The contaminations were usually fungal, but bacterial infection was not uncommon. The bacteria were usually cocci or spore-bearing rods of *subtilis* type; but on one occasion mycobacteria were obtained, and on two occasions yellow organisms resembling those found in streak infections. These were probably all aerial in origin; it is not unusual here to find similar yellow bacterial contaminations in work which has no connection with streak.

The plants under their unusual conditions developed good symptoms in 8–10 days, a slight increase in the incubation period above the normal, probably due to the slower growth of the plants. Mottling of the leaves was marked and occurred in almost every case. Necrosis was not always obtained, and typical streaking of the stems was rare, but streaking of the petioles and necrotic patches on the leaves was common. It sometimes happened that in the same flask one plant had well-marked necrosis, and another had mottle only without true streak; a small proportion of the plants died.

Two to three weeks after appearance of the symptoms the flasks were opened and the plants examined bacteriologically. The whole plant (sometimes two together) except the root system was minced and crushed in broth or Dunham's solution, and after 2–4 hours plates of standard agar and also of potato agar were prepared, pieces of crushed tissue being always included on the plates. The plates and broth (or Dunham) tubes were incubated at 25° C. Uninoculated plants were similarly treated.

The results of a single experiment may be given as an example. Twenty sets of plates were made from thirty-two inoculated tomatoes. Of these seven contained fungi, seven showed bacterial growth (which was neither yellow nor mycobacterial but was curiously fenestrated as if from the action of a bacteriophage); six were wholly sterile. The six sterile sets represented nine inoculated plants. Six sets of plates were made from six uninoculated plants; of these two gave fungal growth, two fenestrated bacterial growth, one both bacteria and fungi, and one only was sterile. At the same time five sets of plates were made from twelve inoculated tobaccos. Of these three gave fungal growth, one bacterial growth, one only was sterile. Three sets of plates were made from uninoculated tobaccos; of these two were sterile.

In all 137 tomatoes were inoculated, and examined, the number of tobaccos was much smaller. In the case of tomatoes 30 per cent. of the inoculated plants remained completely free from bacteria or fungi, although showing well-marked symptoms; from tobaccos only 20 per cent. sterile sets were obtained. These proportions are low for reasons given already. If one included in the figures the sets where fungi only without bacteria were present, the proportions would be much higher, but it is better to count them on the other side. They are enough to establish the facts that it is possible to obtain well-marked signs of streak disease without the appearance of the bacteria usually associated with it in the ordinary conditions of growth, and that when the plants are grown under aseptic

conditions throughout, these bacteria do not develop. Nothing has been found to indicate that these organisms are derived from the virus, or the virus from these organisms.

I have pleasure in acknowledging assistance given me by Miss H. van Straaten, of Wageningen, in some of the experiments made in 1931.

SUMMARY.

From the necrotic tissues of tomato plants suffering from streak, a virus disease, it is possible regularly to obtain bacteria which belong to one or both of two definite types. The same bacteria are to be found in tobaccos infected with the same disease.

If the plants are grown from sterile seed under aseptic conditions throughout and inoculated with bacteriologically sterile virus-holding streak juice, these bacteria do not appear although the plants develop well-marked signs of the disease.

No evidence has been found that the bacteria are derived from the virus or the virus from the bacteria.

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(Received July 11th, 1932.)

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